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Project Engineer

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Major, USAF
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AD INEXPLORATA

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EDWARDS AIR FORCE BASE, CALIFORNIA
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE

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ABSTRACT

This report presents the results of three distinct engine evaluation programs:

1. Evaluation of YJ engine component improvements, many of which are common to the J engine.
2. Evaluation of J engines in the production configuration now being delivered in the first operational T-38 aircraft.
3. Most recently, evaluation of a modified production J engine (General Electric "Operation Nutcracker").

Significant improvements in engine operation were noted in these evaluations over YJ engines used during the Category II systems tests. Modifications tested will bring the J engine up to a reasonably acceptable power plant from an operational standpoint; however, certain component deficiencies still limit the service life.

Evaluation of the production J engine indicates that the first stage turbine nozzle and combustion liner service life is very short. Also, excessive oil venting occurred on all engines. Production J engines had the following operational deficiencies for which fixes were later tested:

1. Low afterburner relight dependability below .85 indicated Mach number (IMN) at altitudes above 35,000 feet.
2. RPM rollback (rapid decrease in engine speed with throttle in fixed position) and frequent engine flameout during throttle burst from idle to full afterburner below .80 IMN at 35,000 feet and above.
3. Marginal engine airstart capability below .70 IMN above 29,000 feet.

The J engine modifications provided improved operation in all the above areas with the following results:

1. Afterburner lights are reliable to 50,000 feet above .90 IMN, and throughout the flight envelope below 40,000 feet.
2. RPM rollback and engine flameout during throttle burst from idle to full afterburner was eliminated below 40,000 feet within the normal flight envelope and significantly improved above 40,000 feet.
3. Reliable airstarts were made at 30,000 feet above 200 knots IAS (.54 Mach).

Two serious deficiencies exist in the modified J engine which should be corrected; engine stalls and/or flameout occur in cruise flight conditions during throttle movements from cruise power to military or afterburner power while at high altitude and low indicated airspeeds; and, hysteresis in engine operating parameters has been a problem on all J and YJ engines. Some reduction of hysteresis was seen in the modified J engine but it is still not adequate to allow pilots to easily set optimum cruise power settings.

TACAN operation was not reliable and could not be evaluated during the program.

This report has been reviewed and approved

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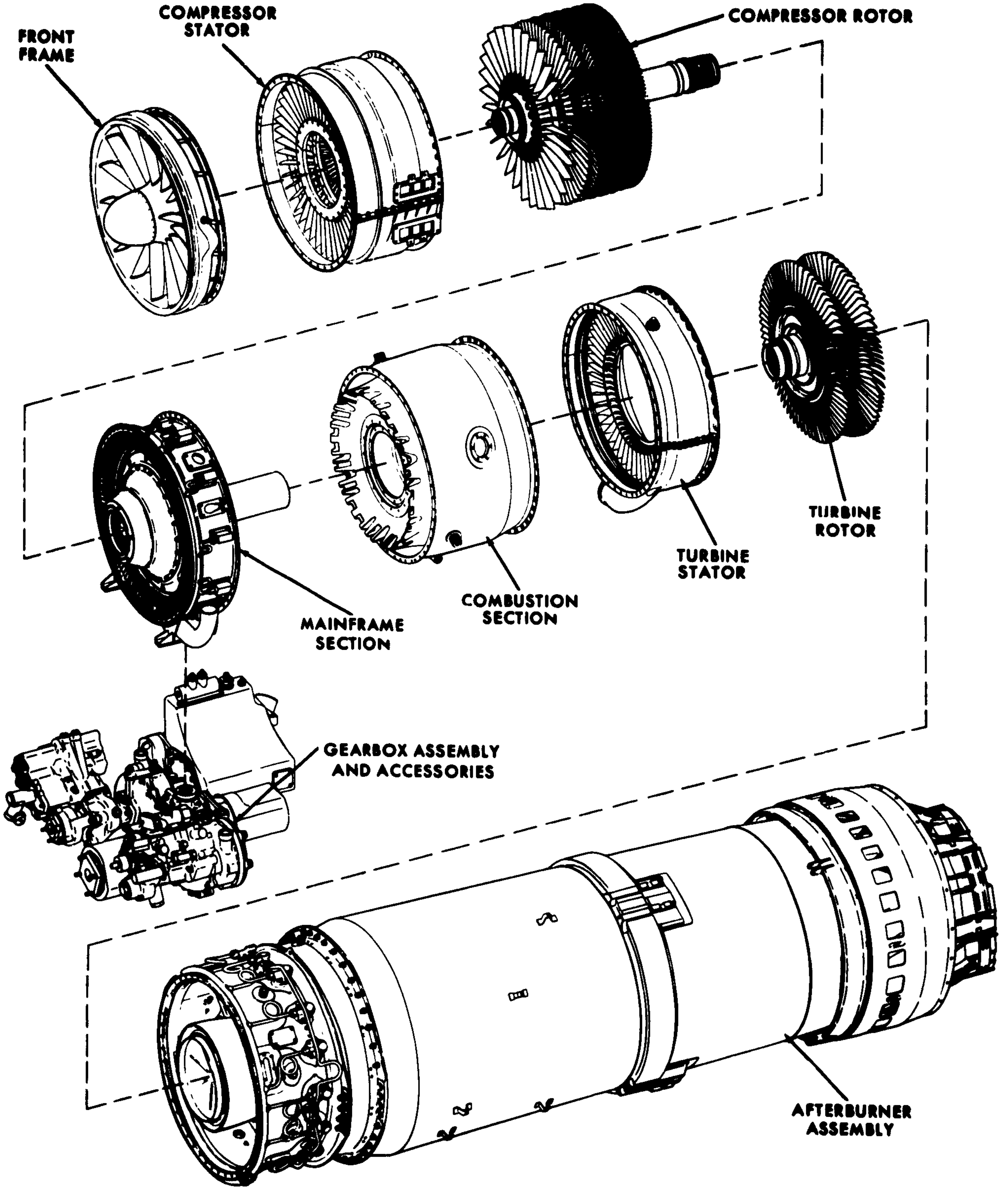


MAJOR ENGINE SECTIONS

IMPROVED YJ85-GE-5 ENGINE EVALUATION

INTRODUCTION

This test was initiated as a follow-on program to the recent T-38A Category II systems tests under authority of ARDC Joint Test Directive Number 58-14. Two YJ85-GE-5 engines (S/N 230-133 and 230-167) were assembled for the service test program, using the late YJ and J engine parts. The objective of this portion of testing was to prove the flight reliability of improved YJ engines and to determine the reliability of the J engine configuration as early as possible. The test began on 1 February 1961 and ended 2 March 1961. Service test engine components were:

1. Compressor bleed valves (P/N 37D401284P101), actuator flexible cables (P/N 37C301397P 104, 37C301397P105, and 37C30 1397P106), variable nozzle actuators (P/N 37D501263P103), afterburner fuel pump (P/N 37D401335 P103). These were J engine components.

2. The exhaust gas temperature (T_5) servo motor (P/N 574D557P 3M) which operates the variable exhaust nozzle incorporated an improved gear train.

3. The variable exhaust nozzle leaves were coated with solid film lubricant.

4. The latest afterburner pump drive pad seal (P/N 37B201650P 109) and mating ring (P/N 37N201 689P101) were installed.

5. A new type main lube pump "O" ring (P/N 37B201207P108) was installed.

6. New afterburner liners and nozzle dams were installed on new afterburner casings.

7. The afterburner control (P/N 37R60191007M2) had a reduced pilot burner flow schedule (.030 inch orifice).

8. The main fuel control (P/N 102R828010A) installed on engine S/N 230-133 incorporated a lighter metering valve spring and trim bellows to prevent engine overspeed during climb. The minimum fuel flow schedule was increased to prevent flameouts during stall approaches.

TEST PROGRAM

The test program included stall approaches, afterburner lights and blowouts, and evaluations of fuel control modifications for preventing engine overspeed, and an accumulation of operating time on installed overspeed governors. Governor operating time totalled 25:10 and 10:35 hours. Engine S/N 230-133 was flown 23:35 hours and engine S/N 230-167 was flown 29:40 hours during the program.

FUNCTIONAL AND OPERATIONAL ANALYSIS

Stall Approaches:

Engine flameouts during stall approach demonstrations were common on the YJ engine. This occurred between 35,000 and 25,000 feet at 130 to 175 knots IAS with the throttle at the "IDLE" position. General Electric Company determined that an increased minimum fuel schedule would correct this problem. One fuel control installed on engine S/N 230-133 was rescheduled to give a 250 pph minimum fuel schedule instead of the previous 175 to 225 pph minimum flow. Fifteen stall approaches were performed by several pilots and no flameouts occurred. One throttle was kept above idle to prevent possible dual flameouts. This test was repeated with the unmodified engine throttle at "IDLE" and flameouts were encountered indicating an improvement had been made. This was verfied in the J engine program.

Afterburner Operation:

An afterburner control with reduced pilot burner flow schedule giving flow rate similar to the J engine control was installed to improve afterburner operation. Nozzle dams were installed on the afterburner exterior to reduce blow-back of high temperature exhaust gases into the engine bay. This lifted a 45,000-foot altitude restriction which had been placed on YJ engines because of excessive temperatures in the engine bay.

The afterburner relight envelope was found to be not significantly improved by these modifications and was still unsatisfactory.

Reliable afterburner relights were not possible above approximately 32,000 feet altitude. The altitude at which afterburner blowout occurred during climb was significantly improved and the afterburner would continue to operate up to 50,000 feet, the maximum altitude at which the aircraft was operated. As the aircraft was slowed down to 190 knots IAS or below at 50,000 feet altitude, the afterburner would flameout; however, this was at or near the low-speed limit of the operating envelope.

Fuel Control Modification for Overspeed:

During evaluation of YJ engines, a slow increase in engine speed above 100 percent rpm was exhibited by several engines. Analysis of this condition by General Electric Company determined that because of engine vibration a resonant condition of the main fuel control metering valve spring caused the fuel schedule to shift upward. Due to the reduced fuel requirements at high altitude, the percentage of fuel flow shift was greater than that experienced on the ground or at low altitude. The main fuel control governor does not compensate for the additional fuel. T.O. 2J-J-85-550 provided a vibration damper kit between the engine gearbox and the main fuel pump. This provided a noticeable improvement but installation was quite critical. Installation of a light metering valve spring and trim bellows on one engine resulted in essentially no overspeed in climbs to 50,000 feet. Based on this limited flying program, this fix was considered more effective than the vibration damper kit in eliminating speed creep. General Electric Company tests on engine S/N 230-131, which had a history of overspeed, demonstrated that this fix eliminated overspeed due to the resonant condition. Overspeed was repeatable on this engine when in a standard configuration. This was quite significant because overspeed had been unpredictable on most other engines used in follow-on Air Force tests.

Overspeed Governor:

Because of possible destructive overspeed on the YJ engines, Woodward Isochronous Governors were provided for service test. The limited flying on this program gave satisfactory results. Because of a 110 percent rpm overspeed incident on a J engine, installation of the governors was accomplished at an early date and all operating experience gave good results. Governors are being installed on all J engines under ECP 85-M-1.

Reliability:

There were no failures of the improved YJ or J engine parts during this phase of the follow-on program. The engines were operational when removed and S/N 230-133 was installed in a Norair flight test aircraft to accumulate additional time.

Numerous power pack failures during the Category II system test were attributed to binding and high torque conditions during opening and closing of the afterburner nozzles. The torque required to open and close the nozzle was found to have been reduced to one-half or less on the improved YJ engine. Considerable improvement in service life of critical nozzle actuating components, particularly the nozzle drive power units, is expected because of this reduction in drive torque required.

CONCLUSIONS

1. The increased minimum fuel flow schedule eliminated the engine flame-out problem during aircraft stall approaches.

2. The afterburner modifications did not improve the light characteristics but did raise the altitude limits for operation without afterburner blow-out.

3. The metering valve springs and and trim bellows used for these tests eliminated metering valve spring resonance causing engine overspeed.

4. All of the tested components were still in good condition at the end of the limited test period.

PRODUCTION J85-GE-5 ENGINE EVALUATIONS

INTRODUCTION

This report presents the results of an accelerated evaluation of the production J85-GE-5 engines installed in two early ATC T-38A aircraft, USAF S/N 59-1603 and 59-1605. Previous evaluation of the T-38A aircraft was accomplished using the YJ85-GE-5 engine, reference AFFTC TR-61-21. Major differences of the later aircraft, other than the engines, are the revised instrument panel, the use of TACAN AN/ARN-21 as the navigational aid in place of the VOR System, AN/ARN-14, and the AIC-18 intercom system replacing the AIC-10. These aircraft were diverted to Edwards Air Force Base, California, from the contractor, Northrop Corporation, Norair Division, Palmdale, California, during the period 10 February 1961 through 1 May 1961. The aircraft were then delivered to the Air Training Command, Randolph Air Force Base, Texas.

The test program was conducted under the authority of the Air Force Systems Command, T-38 Joint Test Directive Number 58-14 dated 17 December 1958.

The Test Plan was written according to the concept of AFR 80-14, dated 19 August 1958, and coordinated with the Air Training Command, the prime using Command. The test had an AFSC priority of 1-B and a precedence rating of V-70 under the development plan for Support System T-38A.

Four engines were flown during this test. A fifth engine, S/N E230-194, (obtained as a spare) was later used for parts and was not flown. In order to obtain 100 hours on one engine, the engines were moved from one aircraft to the other as maintenance schedules allowed until the program was finished. Differences between the YJ engine and the J engine tested in this program are included in Appendix II.

Engine operating limitations under which the test was conducted are included below:

<u>Engine Operating Limitations:</u>

1. Steady-state operation in the 50 to 58 percent RPM range was prohibited.

2. Afterburner operation was not to exceed:

   a. The following nozzle position indications:

      (1) Inflight — 85 percent

      (2) Ground operation or take-off — 95 percent

   b. A 1 minute time limit when on the ground.

3. Maximum allowable overspeeds were:

	Ground -°/o	Inflight -°/o
Transient	106	107
Steady-state	102	104

4. Maximum allowable exhaust gas temperatures were:

Transient	980 degrees C for 0 seconds 825 degrees C for 6 seconds 740 degrees C for 12 seconds
Steady-state	685 degrees C

5. Maximum allowable times were:

Maximum power	5 minutes
Military power	30 minutes

6. Oil pressure limitations were:

Maximum	50 psig
Minimum	5 psig

Aircraft time flown during the test program:

	Received	Test Hours Flown
Aircraft S/N 59-1603	10 Feb 61	78:30
Aircraft S/N 59-1605	28 Feb 61	58:40
		137:10

Total engine flight times at completion of the test including time prior to delivery of test A/C to the Air Force:

	Total Flight Hours
Engine S/N E230-189	100:15
Engine S/N E230-190	77:15
Engine S/N E230-191	44:35
Engine S/N E230-192	66:40
Engine S/N E230-194	0 (spare)

Engine Description:

The J85-GE-5 engine has an eight-stage axial flow compressor, a through-flow annular combustion chamber, a two-stage turbine, an afterburner, and an infinitely variable iris-type converging exhaust nozzle. The major engine sections are shown in an exploded view in Figure 1. Estimated uninstalled minimum sea level static thrust is 2500 pounds at military power and 3850 pounds at maximum afterburner power with an airflow of 42.3 pounds per second. Engine inlet diameter is 16.0 inches, overall length is approximately 104 inches, and dry weight is 550 pounds including the overspeed governor.

Figure 2 shows test engine S/N E230-194 installed on a T-38 engine removal stand.

The compressor has a total pressure ratio of 7:1 and is provided with controlled inlet guide vanes and interstage bleed valves. The inlet guide vanes have a hinge-type design, are infinitely variable, and are scheduled from 0 to 35 degrees closed as a function of percent of corrected engine speed and compressor inlet total temperature. The interstage bleed valves, also infinitely variable, are mechanically linked with the inlet guide vanes and are scheduled to be closed or open when the inlet guide vanes are open (0 degrees) or closed (35 degrees), respectively. Both the inlet guide vanes and bleed valves are controlled by a cam and servo mechanism in the main fuel control. The cam provides the guide vane and bleed valve relationship with percent corrected engine speed. Four ports for extraction of compressor discharge air are located in the main frame of the engine. The annular combustion chamber consists of an outer and inner combustion liner located between the outer and inner combustion casing. Air from the compressor reaches the annulus of the liner through louvers in the outer and inner liner and cools the outer and inner casing in the process. Fuel enters the annulus of the liner through 12 dual orifice nozzles.

The afterburner includes a diffuser, a single V-gutter pilot-burner which acts as a flameholder of the main afterburner flame front, and a fuel injection system. Double wall construction of the tailpipe allows cooling of the outer shell by the turbine discharge gases during afterburner operation. The fuel injection system consists of 4 pilot-burner fuel spraybars and 16 afterburner fuel spraybars.

The variable area primary nozzle is attached to the rear of the afterburner and consists of 12 overlapping leaves joined by a unison ring. This unison ring is actuated by three screw jacks mounted on the afterburner casing and driven by a power unit located on the accessory drive gear casing.

The integrated control system consists of a main and an afterburner fuel control, both operated by a single power lever. The main fuel control meters fuel as a function of engine rotor speed, compressor discharge static pressure, compressor inlet temperature, and power lever position.

The afterburner fuel control meters fuel as a function of power lever position and compressor discharge static pressure. Metered fuel is limited to a safe value for a given position of the exhaust nozzle. Exhaust nozzle position is mechanically scheduled by power lever position during both non-afterburner and afterburner operation. However, a turbine discharge temperature signal is used in conjunction with a temperature amplifier and a power source to override the signal from the power lever whenever the turbine discharge temperature exceeds a predetermined reference value. Thus, the nozzle is positioned to give a safe value of turbine discharge temperature.

TEST PROGRAM

This test was initiated to accomplish a Safety of Flight reliability and functional evaluation of the production J85-GE-5 engine in the latest configured T-38 aircraft.

The program was divided into six primary objectives:

1. Determine the engine airstart envelope.
2. Determine the afterburner relight and blowout envelope.
3. Investigate engine acceleration and deceleration characteristics on the ground and in flight.
4. Investigate aircraft stall approaches to determine engine flameout characteristics.
5. Fly profile missions for qualitative performance comparison between the YJ and the J engines.
6. Accomplish 100 hours flying with teardown inspection on test engines at 50 hour intervals.

A secondary objective was to evaluate navigation equipment and other cockpit modifications incorporated in the production aircraft.

OPERATIONAL ANALYSIS

No special instrumentation was installed in the test aircraft and all information gained was recorded from the standard instrument panel installed in the Category III aircraft.

The J85-GE-5 engine installed in the Category III aircraft has increased thrust over the YJ engine installed in basically the same airframe used for Category II testing. The additional thrust noticeably increased acceleration during take-off and decreased take-off distance by approximately 600 feet.

Based on test day values maximum power climbs to 35,000 feet required an average of 2 minutes, 50 seconds versus 3 minutes 15 seconds for the YJ engine and approximately 4 minutes 30 seconds to 45,000 feet versus 5 minutes for the YJ engine. The additional thrust also increased the V_{max} from 1.17 indicated Mach number (IMN) to 1.27 IMN in level flight at 35,000 feet altitude.

The following information presents the results of specific tests performed to define the capabilities of the J85-GE-5 power plant as installed in the production version of the T-38A. Included are engine airstart, afterburner operation, engine acceleration and deceleration, RPM drift, engine control hysteresis, T-5 amplifier instability, and stall approach test results plus comments on other problems.

Airstarts:

An inflight engine restart program was flown to define the altitude-airspeed envelope of successful air restart capability and was compared to the predicted contractor envelope. Four hundred airstarts were attempted at altitudes from 5,000 to 31,000 feet and airspeeds from 145 to 540 knots IAS. Figure 3 is a plot of airstarts showing range of conditions tested, super-imposed on the uninstalled engine airstart specification envelope. Near the low speed and high altitude edges of the envelope, many hanging starts were encountered and the probability of a good airstart was low. A successful airstart in these areas could always be achieved by lowering the nose and gaining airspeed to increase the engine speed. Airstarts were classified as good, hanging, or no light. A hanging airstart occurred when the engine appeared to light and the RPM increased to a value less than 32 percent but would not reach flight idle RPM unless the aircraft speed was increased by a shallow diving maneuver. The tests demonstrated that the restart capability of this engine-airframe combination is generally satisfactory; however, the envelope does not quite match the high altitude performance envelope specified by the Air Force and the restart performance has decreased in the slow-speed, low altitude area when compared to the YJ start envelope.

The tests were conducted in the following manner:

1. The aircraft was flown in the desired configuration at the required test airspeed and altitude with one engine windmilling and the other engine operating as required to maintain test conditions. Indications of a windmilling engine are 2 to 3 psi oil pressure, zero fuel flow, 90 percent nozzle position, and windmill RPM from 8 to 32 percent, depending upon speed and altitude.

2. After the windmill RPM was stabilized, the ignition switch was actuated and the throttle placed in the idle position. The time between actuation of the ignition switch and engine light varies from 2 seconds at higher airspeeds to 25 seconds at extreme conditions. Indication of an engine light was given by an increase in RPM from the windmill value and a fuel flow rate of 200 pph. The EGT may indicate slightly above the 100 degree Centigrade mark but increasing RPM is the first indication of an airstart at higher altitude. If both engines are flamed out, the only indication of a start will be on the tachometer until the generator cuts in at or about 46 percent RPM. At this time, power will be provided for the fuel flow, oil pressure, and EGT instruments.

When attempting airstarts at higher altitudes during dual engine flameouts, the tachometer should be monitored for the start indication and a start should not be expected in less than 30 seconds. If the RPM is increasing a start is in progress and the throttle should not be stopcocked. The time required for the engine to accelerate to idle RPM varies (depending on altitude) from 5 seconds at high speeds (500 knots IAS) to 50 seconds at low speeds (160 knots). By comparison, ground static starting time for the engine varies from 15 to 17 seconds. Starting time is defined as the interval between actuation of the start switch and stabilization of RPM at flight or ground idle. (7)[1]

Shown in Figs. 4, 5, and 6, and described below, are the maximum EGT during a start, the windmill RPM, and the time required for an engine to accelerate to idle RPM at various altitude-airspeed conditions at which the airstarts were attempted.

Maximum transient EGT recorded during restarts was 680 degrees C which is within the 685 degrees C maximum operating temperature and much below the transient temperature limits. Peak starting EGT varies from 680 degrees C at low speeds (200 knots IAS) and low altitudes (5,000 feet) to 200 degrees C at high speeds (450 knots) and higher altitudes (25,000 feet) (Fig. 4).

Thirteen percent RPM is the minimum windmill RPM for successful airstarts at all altitudes within the contractor's envelope (Fig. 5). Marginal or hanging airstarts were made at windmill speeds of 11 percent to 13 percent RPM, and at altitudes above 29,000 feet; airstarts below 11 percent RPM were rare.

[1]Numbers indicated as (7), etc., represent the corresponding recommendation numbers as tabulated in the Recommendation section of this report.

Approximately 90 percent of the successful airstarts were achieved within 40 seconds of initiation and no start attempts were continued over one minute. Figure 6 shows that increasing altitude and decreasing airspeed tend to increase the time for a successful airstart while high speed, low altitude airstarts are achieved within 5 seconds. The large amount of scatter in the data at higher altitudes is a result of the difficulty in determining when the engine had stabilized after the slow accelerations normal in high altitude starts.

Afterburner Operation:

A series of 326 afterburner lights were attempted to develop the altitude airspeed envelope where successful relights can be expected. Attempted lights were made at each airspeed and altitude condition by smoothly moving the throttle directly from military power into the afterburner position. In addition, lights were attempted by a throttle burst technique from military power and from the idle position to full afterburner position. At the higher altitudes pilot technique was quite important in achieving a successful afterburner light. In one instance, the burst technique would be successful on one engine while on the other engine only a slow retardation from full afterburner position would achieve a light.

The time for an indication of an afterburner light is approximately 2 seconds while the average time for stabilization of the light is 8 seconds. Afterburner light times at altitudes above 40,000 feet and below .7 IMN have been as high as 15 seconds.

No positive afterburner light envelope can be defined because of the rollback problem discussed below under the heading of Accelerations. However, a curve is shown on the accompanying graph (Fig. 7) which separates the altitude-airspeed regime where afterburner relight success is improbable from that where the probability is high. Although this performance is slightly better than the YJ engine, it can be seen that the capability of this configuration is unsatisfactory. Afterburner lights must be possible throughout the usable performance envelope of the aircraft. (3)

After climbs to 50,000 feet with both boost pumps on, the afterburner would blow out unpredictably at airspeeds below 210 knots IAS. This blowout problem existed during straight and level flight or during turns into or away from the afterburner which blew out. Frequently, the engine would flameout when the afterburner blew out.

Engine Acceleration and Deceleration Characteristics:

To define the altitude-airspeed conditions at which adverse engine performance results from rapid throttle movements, 284 recorded engine accelerations and 226 decelerations were accomplished. These tests were accompished by making one second, smooth, throttle movements from idle to full afterburner and from full afterburner to idle during level flight and in descending turns at various speeds and altitudes.

The response of the engine to rapid increases of the throttle at altitude was not satisfactory. During burst accelerations to military or maximum power at or slightly below the rollback line on Fig. 7, the engine RPM would oscillate for 3 or 4 seconds about a point (94 to 97 percent) less than the normal RPM level and then slowly reach a stabilized normal condition. Above this line on the same figure, severe rollback of engine speed would occur without the afterburner becoming lit. If the throttle was not quickly retarded to idle as the engine RPM decreased through 80 to 70 percent RPM, the engine would consistently flameout. Engine overspeeds on bursts reached a maximum of 102.5 percent. (3)

Inflight compressor stalls have occurred on 20 occasions when the throttle was retarded rapidly from full afterburner to idle (throttle chop). Conditions under which these stalls are likely to occur on a chop are above

30,000 feet and below a .65 IMN. The indication of the stall varies from a weak chugging noise to a loud woofing sound; however, the engine recovers immediately to idle and only one flame-out occurred during these stalls. (3)

Engine overspeeds of 103 percent were recorded on chops at speeds over 1.0 IMN.

The ground engine acceleration RPM "hang-up" problem peculiar to the YJ engine is not present in the J engine and the time for acceleration from idle to military power averages 7 seconds without "hang-up" or hesitation.

RPM Drift:

The engine RPM drifts consistently during climbs and dives at military power. On all climbs, engine speed droops at intermediate altitudes from the take-off power setting then increases to an overspeed condition at higher altitudes. Extremes of 97.0 percent to 102 percent were noted. During high speed dives, engine speed increases to a steady state value as high as 102.5 percent. The rate of RPM change is not rapid and takes place over the full range of altitude flown. (4)

Engine Control Hysteresis:

Nozzle positions and EGT values differed significantly between any two engines installed in an aircraft while at the same RPM setting. This difference also occurred on each engine at any given RPM value according to the forward or aft direction of throttle movement used in reaching the desired RPM setting. This situation is undesirable in obtaining efficient cruise operation since engines cannot be matched by use of the tachometers. (6)

Exhaust Gas Temperature (T_5) Amplifier Instability:

The (T_5) amplifier is not sufficiently sensitive to damp nozzle variations while in military power above 35,000 feet. Nozzle hunting indications concurrent with EGT, fuel flow, and RPM variations are mentally distracting to the pilot and should be eliminated. In some cases the nozzles were so unstable that noticeable power surges could be felt by the pilot as the nozzle changed position. This deficiency is not only operationally undesirable but functionally unsuitable from a maintenance viewpoint. (5)

Stall Approaches:

Engines were tested at flight idle conditions at all altitudes from 45,000 feet to 15,000 feet down to speeds where airframe buffet was encountered. No engines stalled under any of these conditions. This is a marked improvement over the YJ engine.

Fuel Boost Pump Operation:

After servicing the system with fuel at normal temperature (65 to 70 degrees F), four climbs were made at recommended climb schedule with one fuel boost pump off to outline the operating limits of gravity feed.

The first and third climbs were performed with the right fuel system boost pump off and the second and fourth with the left system boost pump off. Maximum power was used during the climbs to the maximum altitude at which gravity feed would sustain smooth afterburner operation. On the first climb, the right engine operated in afterburner normally until 37,000 feet where engine instruments indicated surging and at 40,000 feet the afterburner blew out and,the engine flamed out. The second climb proceeded normally again to 37,000 feet, where engine instrument fluctuations began. The left afterburner was manually cut off at 40,000 feet and the engine speed dropped to 95 percent RPM in military power at 42,000 feet where engine instruments again began to fluctuate. At 45,000 feet the left boost pump was turned "ON" and RPM jumped 2 percent and fuel flow increased from 450 RPM to 600 pph. The last two climbs with a single boost pump off verified the altitudes and indications mentioned above. These tests indicate that gravity feed will sustain afterburner and military power engine operation a intermediate altitudes for flight to an air base without creating an emergency situation.

Engine Overspeed:

One incident of engine overspeed occurred during flight and was attributed to failure in the main fuel control. The engine had flamed out at 47, 300 feet during an afterburner climb. Subsequent attempts to airstart the engine during descent resulted in an RPM increase to approximately 100 percent RPM while the throttle was in the idle position. At 15, 000 feet on the final airstart, the throttle was stopcocked as the engine accelerated through 85 percent RPM (above flight idle) but it continued to 105 percent RPM before deceleration to windmill RPM.

Analysis of the control revealed the governor pilot valve drive stem was sheared and the piston seized in the increase RPM position. Seizure was primarily caused by contamination in the form of a gummy substance in the vicinity of the piston stem. Also small metal particles were found in the same area. The engine contractor's analysis of this failed fuel control pointed out that the overspeed condition encountered could have reached 110 percent RPM.

This incident clearly illustrated the need for a positive fuel governing device to guard against uncontrollable high engine RPM associated with internal fuel control failures. This type of fuel control failure was not experienced during the 1200 hour Category II program. It further demonstrates the lack of fail-safe design which was experienced during that program and led to the development of the overspeed governor mentioned previously under the improved YJ engine development program. All J85-GE-5 engines were subsequently fitted with overspeed governors (Woodward Isochronous Overspeed Governor, P/N 37D40158P101) as directed by the T-38 Project Office at Aeronautical Systems Division. Over 100 hours were flown with the two test aircraft using these overspeed governors without further incident.

Another incident of governor failure in the main fuel control occurred on engine S/N 230-185 which was to be used on a T-38 during performance test. The engine either would not start or started very slowly and stalled. A bench check of the main fuel control revealed metal particles in the fuel filter. It was determined that the speed pilot valve T bar was broken causing the speed pilot valve to be driven intermittently, particularly during starts (UR 61-119). This failure is identical to that experienced during the J engine evaluation, except that the pilot valve piston was stuck in the low RPM position.

The use of an external overspeed governor is considered a requirement until such time as the J85-GE-5 main engine fuel control is qualified to fail-safe in the event of malfunction or failure.

Oil System:

The main problem experienced with the oil system was excessive loss of engine oil. The ground handling and servicing manual, T.O. 1T-38A-2-2 does not specifically state when the engine should be serviced with oil so that the dip stick reading will reflect the proper oil level in the reservoir.

It was found that servicing oil within 10 minutes after engine shutdown resulted in less oil being vented overboard during flight. There is a difference of one pint of oil between servicing at 10 minutes and servicing at 30 minutes after shutdown because of oil draining into other parts of the engine.

To isolate this venting problem the engines were serviced to the dip stick "full" line after having been shutdown for 30 or more minutes. Subsequently, flights of 1 hour duration were made, and 1½ to 2 pints of oil were required to replenish the oil level. This occurred on the same engines that had previously used only ½ pint or less oil during a 1 hour flight when oil was serviced within

10 minutes after engine shutdown. When flight duration exceeded 2:00 hours, the engine oil consumption was very close to the 0.60 pound per hour specified in T.O. 1T-38A-2-6 when oil servicing was done within 10 minutes after engine shutdown following flight. This consumption rate was reduced slightly by allowing the oil level to remain approximately one pint below the "full" mark, as checked immediately after shutdown. Tank overboard vent line pressure relief valves were checked for possible sticking and were found to be satisfactory. The oil consumption experienced when servicing up to the "full" mark on the dip stick within 10 minutes after engine shutdown appears to be a problem of venting overboard (evidenced by excessive oil on the fuselage). This deficiency must be corrected to allow a safe margin for engine deterioration and to reduce engine servicing requirements. From this study it is apparent that the servicing manual is deficient in presenting a clear cut method for servicing the engine oil (MIL-L-7808) and should be amended accordingly. (8 and 9)

Navigation Equipment:

Comparison of the range capabilities of the production T-38 with data obtained during the YJ program was not accomplished because of lack of operational navigation equipment. The two test aircraft were among the earliest of the production block of aircraft which are equipped with an improved instrument display system. The major change was the use of the standard Air Force attitude director indicator (ADI) and horizontal situation presentation that functions in conjunction with TACAN (Tactical Air Navigation) AN/ARN-65 and replaces the earlier J-4 Compass Direction Gyro and VOR (Visual Omnirange) AN/ARN-14 combination. At the time of this test, the equipment had not been qualified in the T-38 aircraft. The TACAN was unreliable because of radio noise interference within the aircraft installed equipment, and the ADI and HSI could not be evaluated under normal range or instrument conditions because the servo amplifier was not compatible with the wide range frequency electrical power source of the aircraft. It was found that the servo amplifier required 380 to 420 cps for operating limits, whereas, the aircraft source varied between 320 and 480 cps. Therefore, when it was necessary to operate the engine at low RPM or below the speed which produced a frequency of 380 cps, the amplifier would become inoperative. This required reslaving action at certain inopportune times such as during an instrument penetration, starting final approach, or passing a ground fix. At the end of this program, the contractor had estimated suitable fixes by 1 August 1961. (10)

FUNCTIONAL ANALYSIS

The J85-GE-5 production engines tested during this program represented a great improvement over earlier YJ85-GE-5 engines. Although this program was a relatively short sampling of follow-on product improvements, it did demonstrate progress in several areas. The program was too brief to perform a complete analysis of deficiencies; consequently, several items will require further investigation as engine time beyond 100 flying hours is accumulated. These items are the variable geometry actuating system, number two and three bearing carbon seals, compressor bleed valves, fuel nozzles and variable exhaust nozzle power pack. These items were problem areas in the YJ engine but were satisfactory in this limited test.

This analysis is the result of teardown inspections of four engines, S/N's 230-189, 230-190, 230-191 and 230-192, at 50 hour periodic inspection intervals. Engine number 230-189 was inspected for the second time after 100 flying hours.

The first sections of results discussed pertain to items originally found during the Category II YJ engine test and re-evaluated using production engines. The remaining discrepancies (last two paragraphs of this section) are classified as new problems peculiar to the J engine.

Variable Geometry Actuating System:

Accelerated wear of the variable geometry (VG) actuating linkage and components - prevalent on the YJ engine - was not encountered on the J engine. The reinforced components incorporated in the production engine held up satisfactorily on engine number 230-189 through the 100 hour inspection. Only one actuator arm was found slightly worn: however, it was within serviceable limits. No discrepancies were found on other test engines.

Number One Bearing Seal Leakage:

Number one bearing seal leakage is still a problem in the production J engine; particularly after shutdown from idle rpm. From a maintenance viewpoint it amounts to a minor nuisance item because the amount of oil leakage is small. One technique used to reduce leakage in the test cell was to operate the engine at 60 percent rpm for about 3 minutes before shutdown. This procedure scavenges sufficient oil to prevent leakage. If the oil is not scavenged, slight traces of oil must be wiped off the inlet guide vanes before flight or oil fumes will momentarily be noticed in the cockpit before take-off. The requirement to operate engines at 60 percent rpm for 3 minutes prior to shutdown to scavenge oil is not acceptable for a trainer aircraft. (11)

Number Two and Three Bearing Carbon Seal:

The number two and three bearing carbon seals were worn excessively after 67 flying hours in engine number 230-192 but were serviceable after 100 hours in engine number 230-189. Further investigation into the durability of these seals is warranted. (12)

Compressor Bleed Valves:

The redesigned compressor bleed valve presented no problem on the J engine. The lack of lubrication caused a high failure rate on the YJ engine. Normal adjustments were required during this test program but no lubrication deficiency was experienced.

Compressor Rotor:

A common problem with the YJ engine was shifting of the rotor assembly which resulted in an out-of-balance condition, runout, and in one instance failure of the seventh stage spacer due to rubbing. This situation was alleviated in the J engine by the use of close tolerance studs in place of the dowel-type method of locating the discs and spacers. These studs provide a more stable assembly, and only a minor amount of maintenance was necessary on these rotors.

Ignition Unit and Igniter Plugs:

The ignition unit on the J engine was redesigned with an increased voltage output, and only one igniter plug was used. This redesigned system was found to be reliable throughout the J engine tests.

Main Fuel Control:

The only major problem encountered with the fuel control was a failure of the internal governor pilot valve. This valve froze in the up position resulting in high fuel flow, which caused an overspeed condition. Binding of the valve was caused by a gummy substance in the valve sleeve. The overspeed governor now installed on the engine will prevent this type of failure from resulting in a serious accident; however, a modification should be made to insure adequate lubrication and clearance between the rotating valve and the sleeve. This type failure had not occurred during YJ engine operation. (13)

There was also one schedule shift in a J main fuel control which was corrected by bench adjustment. This was frequently necessary on YJ controls.

Fuel Nozzles:

The problem of a hole developing between the large slot tube and spacer, and subsequent fuel leak which was experienced with the YJ engines did not recur during the J program. The fillet weld of the spacer and large slot tube alleviated this problem; however, 13 fuel nozzles were rejected for streaks in the spray pattern and four nozzles were rejected for high flow. These nozzles became erratic after approximately 50 hours operation. Continued investigation of fuel flow out-of-limits is necessary. (14)

Afterburner Fuel Control:

One afterburner fuel control malfunctioned after 44 flying hours when low thrust in the afterburner regime was experienced. Bench check and recalibration corrected the difficulty.

Combustion Liners:

The combustion liners on test engines 189 and 192, P/N 37R601230P101, failed beyond the allowable limits for repair of cracks within 50 flying hours. This failure rate is unsatisfactory because of the maintenance impact at such short intervals. Extended limits for repair procedures should be provided or replacement of the combustion liner by section should be authorized. (15)

First Stage Turbine Shroud P/N 37C301186P101:

All test engine shrouds showed wear after 50 flying hours but none were worn beyond technical order limits. Wear appeared uneven due to distortion of the shroud segments under operating temperatures. These segments should be more securely fastened to the turbine casing to limit flexibility. Sufficient operating time was not accumulated on engines to determine the seriousness of this deterioration. The wear appeared to be approximately the same as in the YJ engines in which extensive replacement was required. (16)

Second Stage Turbine Shroud, P/N 37D401175P107:

Tab locks broke on the shroud segments on engine S/N 230-190 at approximately 50 flying hours and the segments rotated, resulting in a binding of the turbine rotor. Engine S/N 230-192 also rubbed in this area but the situation was alleviated by loosening, tapping, and retightening the turbine case to proper torque values. This problem and the corrective procedures were similar on the YJ engine. (16)

Afterburner Assembly:

The afterburner liners on the J test engines were serviceable at the close of this program. Removal and repair was not necessary on any of the test engines. This is a great improvement over the YJ liners.

Riveted attachment of flap seals to afterburner casing showed no sign of wear on J engines. This fix is considered satisfactory.

The use of bolts and nuts for a more permanent method of attachment on the J engine diffuser liner, in place of pins and cotter pins, was satisfactory during this evaluation.

Afterburner Fuel Pump (ABFP):

One afterburner fuel pump, P/N ABP 10230, was removed because of leakage after 44:15 hours of operation. The thrust plate was cracked and had gouged the carbon seal similar to failures encountered on the YJ engine. The better cooling feature for the thrust plate in the newer pump apparently is not sufficient to correct the problem. Leakage around the ABFP mounting pad seals was also a common problem. (17)

Variable Exhaust Nozzle Power Pack:

No shaft failures occurred on J test engines; however, the length of this test is not considered conclusive in determining the reliability of the improved units and their installation procedures.

Exhaust Nozzle Actuator:

The J engine nozzle actuators functioned satisfactorily throughout this program. The early failure trend of the nozzle link (wishbone), P/N 37C30127P101, in the form of bending and breaking, was corrected by the use of a reinforcement of the link. None of the newer links failed during the J program.

The remaining items are new problems peculiar to the J85-GE-5 engine and were not encountered on the YJ engine:

First Stage Turbine Nozzle:

The first stage turbine nozzles required replacement every time an engine was disassembled. As shown in Fig. 8, there was extensive warpage and cracking, both circumferential and axial on the inner band. In one instance a turbine nozzle had to be replaced after only 19 operating hours. The temperature environment in the J engine is higher than that of the YJ, and the nozzle has undergone modification which reduced the airflow to the inner band. This nozzle should be redesigned to obtain increased airflow to the inner band. More freedom of movement should also be designed into the nozzle, either by segmenting or allowing one end of the vanes to float, thus permitting expansion and contraction without cracking or distorting. (18)

Number One Bearing Rotation:

A teardown of engine S/N 230-192 after 67 flying hours was performed to determine the cause of high oil pressure and oil contamination. The number one bearing had rotated in the front frame, generating chips and wearing the mating surfaces. These were also a slight indication of number one bearing rotation in engine S/N 230-189 at 100 hours. The front frame was also damaged by this bearing rotation in both these engines. An interference fit is considered a suitable fix to eliminate this problem. (19)

CONCLUSIONS

1. The objectives of the production J engine test plan were completed with the exception of evaluation of mission profiles which could not be accomplished because of a lack of operational navigation aids in the two follow-on test aircraft.

2. Ground operation of the engine is satisfactory.

3. Engine airstarts were successful below 29,000 feet at 13 percent or higher windmill rpm. High-altitude, low airspeed starts may require more than 1 minute for completion. Using techniques outlined in this report, airstart reliability is extremely high in the envelope defined by Fig. 3.

4. The afterburner light envelope is unsatisfactory and should be extended to cover the operating envelope of the airframe. Nozzle response during an afterburner light is too slow. As altitude decreases, rpm roll back decreases but roll back at high altitudes (low compressor discharge pressures) is excessive and will cause engine flameouts if the throttle is not chopped to "IDLE".

5. RPM drifts excessively on climbs or dives in military power; however, no overspeed condition was reached.

6. Engine performance cannot be matched by use of the tachometers alone because hysteresis effect causes nozzle position and EGT and hence thrust to vary between engines at the same rpm setting.

7. Nozzle hunting above 35,000 feet at military power is excessive.

8. The problem of engine stalls and flameouts with the engine at flight idle during approaches to an aircraft stall has been corrected.

9. Operation with fuel boost pump failure is satisfactory up to intermediate altitudes.

10. The use of an external overspeed governor to prevent destructive overspeed conditions is considered mandatory.

11. Oil servicing instructions are inadequate. Overboard venting of oil is excessive in flight.

12. The TACAN is unreliable and the aircraft should be restricted to VFR operation until reliability of the navigational equipment is proven.

13. There has been a noticeable improvement in the components of the J85 engine over the YJ85 engine; however, some items which must be monitored or corrected include: bearing seals, fuel nozzles, combustion liners, afterburner fuel pumps, and first stage turbine nozzles.

MODIFIED J85-GE-5 ENGINE EVALUATION

INTRODUCTION

As a result of flight tests which brought to light the deficiencies covered in the evaluation of the production J85-GE-5 engine, the General Electric Company instituted a flight test and engineering program called "Operation Nutcracker" designed to improve the operational capability of the J engine. At the conclusion of the company flight test program, six demonstration flights totaling 6 hours and 45 minutes were flown between 15 and 22 May 1961 by six different ATC and AFFTC pilots to evaluate the fixes incorporated in a modified production J85-GE-5 engine.

TEST PROGRAM

Items investigated during the General Electric demonstration flights were evaluated for:

1. Increased afterburner light capability including a check for afterburner blowout up to 50,000 feet and decreased rollback of engine speed at high altitudes and low speeds.

2. Increased airstart capability.

3. Decreased rpm drift in climbs.

4. Damping of nozzle fluctuations in military power setting above 35,000 feet.

5. Decreased hysteresis of EGT and nozzle position at various rpm settings under cruise conditions.

6. Engine stalls at flight idle rpm while aircraft was in stall approach at altitudes from 15,000 to 45,000 feet.

The main objectives of the test were to determine the airspeed-altitude limit to which the afterburner and airstart envelope had been raised. To gain maximum advantage of available flight time, data cards covering the upper flight limits were drawn up by AFFTC engineers based on an inspection of General Electric flight test results. The modified J85-GE-5 engine, S/N E230-022, was installed in the left bay of the General Electric bailed aircraft. Thus engine readings could easily be compared visually by each pilot with a standard engine, S/N E230-222, installed in the right bay. Data from desired test conditions was taken on the left engine only and recorded on data tape and coordinated by radio with a ground controller.

OPERATIONAL ANALYSIS

Afterburner Operation:

The most significant improvement of the "Nutcracker" program was the increase in the ceiling of the idle to afterburner light limit line. As can be seen on Fig. 9, the ceiling has been raised approximately 6,000 feet at an indicated Mach number (IMN) of .5, and approximately 10,000 feet at IMN of .9. The rpm rollback line determined by throttle bursts from military to full afterburner lies essentially along the same line. No afterburner blowouts during the climb or cruise at 50,000 feet were experienced by any of the pilots flying this demonstration. This improvement is considered operationally satisfactory at the current stage of engine development.

However, one major deficiency uncovered in the course of the demonstration tests was engine stall and subsequent flameout at high altitudes and low indicated airspeed during throttle advance from above 90 percent rpm to military or afterburner. This type of throttle movement by wingmen occurs frequently during formation cruise missions. The high probability of engine stalls and flameouts will be detrimental to the completion of this type training; therefore, the deficiency is unacceptable. Initial test data indicate this stall area is defined by a line approximately 2,000 feet below the modified J engine, afterburner-light limit line at 35,000 feet, and crosses this line at 45,000 feet. (2)

Airstarts:

Inspection of Fig. 10 shows that the ceiling for successful airstarts (no hanging starts) has been raised 2000 feet at low speeds and 3000 feet at higher speeds. The new ceiling is considered acceptable since any hanging airstarts occurring near the upper left corner of the envelope can be completed by lowering the nose and gaining airspeed.

RPM Drift:

Visual comparison of rpm drift was made by each pilot on the climb to altitude. All pilots reported drift on the modified engine was 1 percent or less as compared to a range of 5 percent for the unmodified engine.

Nozzle Fluctuation:

Erratic nozzle operation with corresponding variations in EGT readings was very slight at military power setting above 35,000 feet.

Engine Control Hysteresis:

The problem of unmatched nozzle positions at the same rpm settings and consequent loss of thrust was quite prevalent with the J engine. Figure 11 shows the results of the new nozzle area schedule compared to the schedule on the J production engine. An improvement from 20 percent to 9 percent variation in nozzle position over the range of rpm setting from 91 percent to 96 percent is significant when compared to the standard engine. Most cruise conditions exist within the above rpm range and, consequently, the nozzles should be closely matched to achieve maximum performance at a matched rpm setting. (6)

Stall Approaches:

The modified engine was checked for a stall and subsequent flameout at altitudes from 15,000 to 45,000 feet while in the flight condition at airspeeds approaching airframe buffet. No engine stalls occurred during the demonstration program.

FUNCTIONAL ANALYSIS

Modifications made to the engine are described below. Following each modification is a brief description and summary of results achieved by each item. Conclusions drawn on the effectiveness of each item are based on the inspection of General Electric instrumented data.

Speed Derivative Amplifier (dN/dT .1, gain .00125, lead 1.6):

This amplifier is a speed sensing temperature device capable of changing the base temperature reference as a function of engine speed. The amplifier with the settings listed above reduces engine fuel requirements on a transient, improves system stability, minimizes the amount of rollback and reduces recovery time to desired rpm settings. Figure 12 compares the new setting to a standard amplifier on a military to full afterburner light. (1a)

No. 11A Nozzle Schedule:

The 11A schedule shifts the nozzle area flat to a higher position with respect to throttle angle. This assures reaching the idle nozzle position on all retards. The cruise flat has been shifted to a higher throttle angle in order to operate within the 91 to 96 percent rpm range at .9 IMN at 45,000 feet. Figure 13 compares the 11A schedule with No. 9 schedule, the current production item. (1b)

New A_8 (Nozzle Area) Limit Schedule:

The new schedule in the afterburner control limits the flow of afterburner fuel at low compressor discharge pressures (CDP) which gives a smoother light and hence reduces rpm rollback. (1c)

-553 Fuel Schedule:

The new acceleration fuel schedule (553) differs from the production engine version (552) when the compressor inlet temperature (CIT) is 60 degrees Fahrenheit or below and engine speed is 80 percent or above. RPM rollback with the new schedule encounters an increasing acceleration fuel schedule with decreasing engine speed, or the opposite of the 552 schedule. Although the effect on rpm rollback on military to full afterburner transients is not appreciable, a marked difference can be noted in the amount of rpm rollback on idle to military and idle to full afterburner throttle bursts. Inspection of Fig. 14 shows nozzle fluctuation has been eliminated and rpm rollback reduced. (1d)

Optimized Pilot Burner Fuel Flow:

Pilot burner fuel flow was reduced by scheduling a lower flow to the minimum side of the tolerance band. This optimization improved afterburner light capabilities at high altitudes and low Mach numbers without penalizing other areas of the flight envelope. (1e)

Modified Acceleration Switch:

This switch increases the cut in speed for initiation of afterburner fuel flow from 85.5 percent to 89 percent rpm. No conclusive evidence was presented to indicate that this switch operated to prevent rpm roll back.

Split, Balanced, Afterburner Fuel Manifold:

The new manifold was intended to insure equal fuel flow to all spraybars. No measurable effect could be seen with this item.

Pilot Burner Spraybar Heat Shields:

These heat shields were designed to reduce boiling and sporadic loss of flow; however, the effects were not evident in this demonstration.

General Laboratory Associates (GLA) Ignition System:

The new ignition system fires at half the rate with twice the energy of the production system. This enables the plug to fire in more adverse conditions such as a very wet spark plug at high altitude. This is a dual ignition system for engine and afterburner lights, and both will fire on either an engine start or on afterburner light. This ignition system has contributed to the increase in airstart capability seen in Fig. 10. (1f)

High Reliability Afterburner Spraybars:

A new heat treat process and a spring change were made on the afterburner spraybars. No effect on afterburner light capability was noticed during testing.

Light Weight Metering Valve Spring and Trim Bellows:

By changing from a beryllium to a light weight stainless steel spring, the natural frequency of the spring was increased to avoid a resonant condition existing between the beryllium spring and top engine speed frequency. No steady state overspeeds have been experienced with the new spring. (1g)

2.5 PSIΔP Valve, No. 1 Bearing Sump:

General Electric states that the higher differential pressure of this valve eliminated front frame oil leaks on the one test engine used in the program. The 2.5ΔP valve should be re-incorporated in standard engines if this proves effective in other test engines.

0.025 Inch Diameter Orifice, Lube Tank Press:

The original .025 inch diameter bleed orifice was reinstalled in the oil leak vent valve after testing showed that a .050 inch diameter bleed allowed tank pressure to drop below 20 psi at high altitudes.

Thin Mating Ring, Afterburner Fuel Pump Drive Pad:

The thickness of this ring was reduced to eliminate oil and air leaks in the afterburner fuel pump. No positive check was possible to insure that this was an adequate fix during the few available hours of the demonstration flights.

Redesigned Wishbones with Increased Cross Section:

Wishbones (actuating arms on afterburner nozzle control) were strengthened to prevent binding and warping under high dynamic pressure flight conditions. There were no high dynamic pressure maneuvers performed during the demonstration tests.

Recontoured Metering Valve Afterburner Control (ABC):

This metering valve operates in conjunction with the A_8 limit schedule. At low CDP's, the new valve decreases fuel flow which reduces the amount of rpm rollback accompanying an afterburner light. (1h)

CONCLUSIONS

Modifications made to the production J85-GE-5 engine have significantly improved the afterburner light and airstart envelopes over the standard engines tested under the J engine evaluation. The afterburner light envelope has been extended to 220 knots IAS at 50,000 feet and to 180 knots at 40,000 feet. Below 40,000 feet the afterburner capability is satisfactory throughout the airframe envelope. The airstart envelope has been raised 2,000 to 3,000 feet and is satisfactory at 30,000 feet for all airspeeds above 200 knots.

However, a new deficiency, apparently occurring as a result of the modifications, causes engine stalls and flameouts during throttle movements from cruise power settings to military or afterburner while under cruise flight conditions.

CONSOLIDATED RECOMMENDATIONS

The following recommendations are a consolidation of all recommendations covering the three evaluation programs on the YJ and J engines. The latest modified J engine (GE "Operation Nutcracker") test recommendations negate some recommendations concerning the production J engine. The recommendations are, therefore, broken into groups A and B below, one of which should be considered. In either case Group C is applicable and should be incorporated.

A. Operational improvements:

*1. On the basis of improved engine operation in respect to afterburner light capability, rpm roll back, rpm drift, hysteresis of EGT and nozzle position, variable exhaust nozzle system instability, and increased engine airstart capability noted in the modified J engine evaluation, it is recommended that the following items be incorporated in the J85-GE-5 production engine:

*a. Speed derivative amplifier dN/dT .1, gain .00125 (page 18).

*b. No. 11A nozzle schedule (page 18).

*c. New A_8 limit schedule (page 18).

*d. -553 fuel schedule (page 18).

*e. Optimized pilot burner fuel flow (page 18).

*f. GLA ignition system (page 19).

*g. Lightweight metering valve spring and trim bellows (page 19).

*h. Re-contoured metering valve (afterburner control) (page 19).

*2. A deficiency existing in the modified engine that must be eliminated is engine stall and/or flameout while in high-altitude, low-speed flight conditions during throttle movements from cruise power to military or afterburner (page 17).

The other items covered in the modified J engine evaluation section may contribute to overall increased engine capability but did not show a measurable contribution or were not helpful toward the operational problems investigated.

*Indicates that corrective action has been initiated or approved by the ASD project Office.

B. Recommendations in lieu of A above. If the previous recommendations are not incorporated, AFFTC recommends that based on the flight tests conducted the following recommendations be incorporated.

**3. The afterburner light envelope be improved to cover the operating envelope of the airframe. This includes prevention of afterburner blowout at 48,000 feet and above and subsequent engine flameout, elimination of rpm roll back, and prevention of compressor stalls during throttle chops (page 9).

**4. Engine top speed drift be decreased to not more than ±1 percent variation during climbs and dives (page 10).

**5. The T5 amplifier be made more sensitive in order to prevent unstable nozzle actuation at military power at high altitudes (page 10).

C. In addition to A or B above, AFFTC also recommends that:

*6. Throttle hysteresis be decreased at cruise power settings (page 10).

*7. A note similar to the following should be added to the airstart section of the T-38 Handbook:

"Airstarts at high altitude and low airspeed may require 25 seconds or more for light-off and an additional 50 seconds for engine acceleration to idle. With both engines flamed out, there is no a.c. power to the fuel flow or EGT instruments and the only indication that an airstart is in progress is a gradual increase in rpm. Only after the generator cuts in at approximately 46 percent engine rpm do the fuel flow and EGT gages begin to operate" (page 8).

*8. Oil venting in flight be eliminated (page 12).

*9. Specific instructions for oil servicing be included in the applicable T.O. to prevent high oil depletion (page 12).

*10. The TACAN equipped T-38 be restricted to VFR operation only until the system can be made reliable (page 12).

*11. A more positive sealing action be designed into the number one bearing to prevent leakage after normal shutdown. This can result in oil fumes in the cockpit. Consideration should be given to a pressurized seal in this area which would permit adequate scavenging (page 13).

*12. The number two and three bearing carbon seals be carefully evaluated at periodic inspections, on higher time engines for excessive wear (page 13).

*13. The main fuel control be modified to assure adequate lubrication and clearance between the internal governor pilot valve and the sleeve in which it rotates (page 13).

*14. Fuel nozzles be modified to prevent clogging with carbon deposits and flow rate instability which occurs

**Action is beging taken on an alternate recommendation.

after approximately 50 hours operation (page 14).

*15. Limits on repair of combustion liners be increased, or provisions be made for replacement of the liners by sections (page 14).

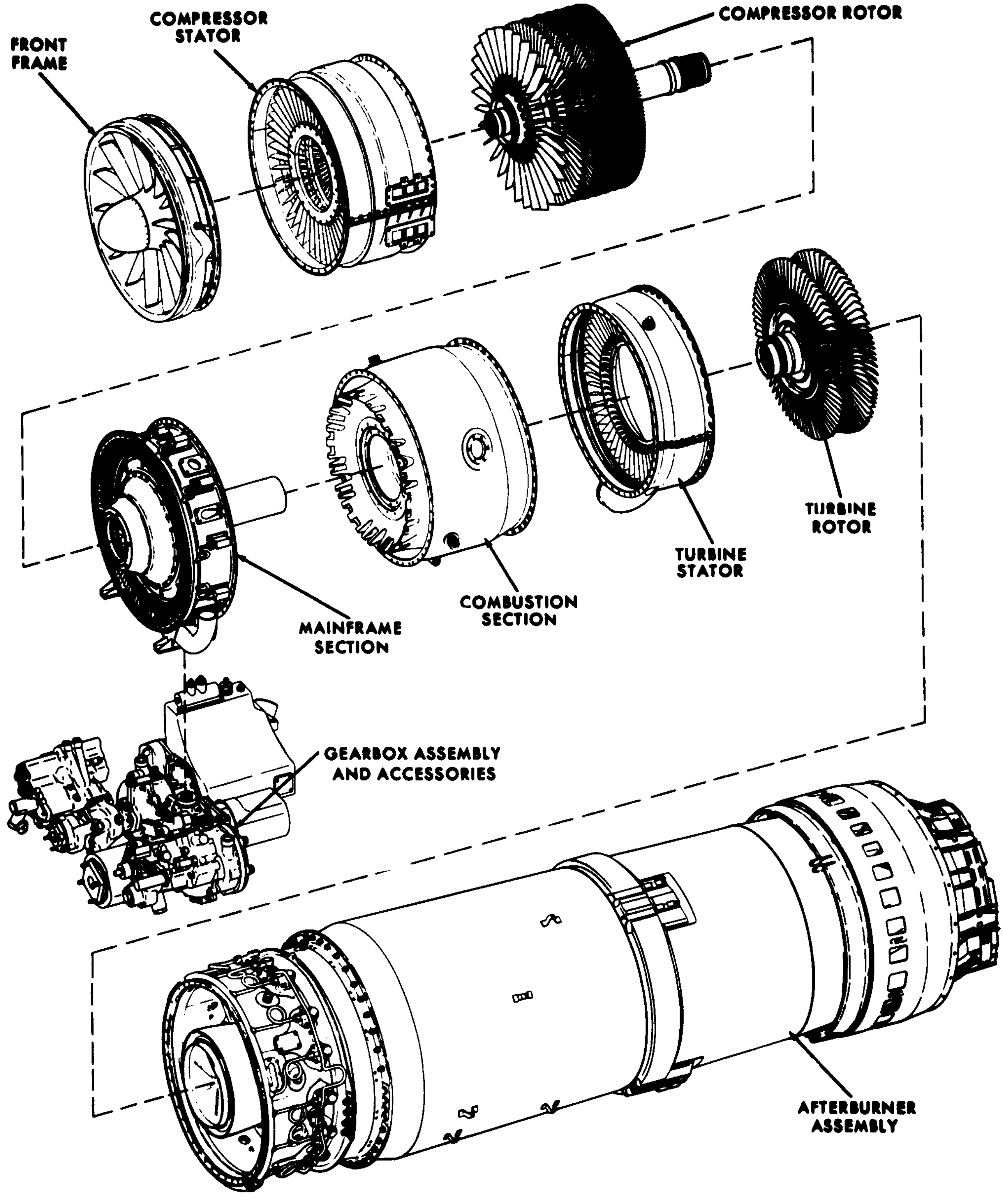
*16. Caution be exercised in assembling the first and second stage shrouds to prevent damage to the tab locks which hold the segments together. The segments should also be more securely fastened to the casing to prevent bowing of portions of the segments which induces rubbing (page 14).

*17. Thrust plates receive greater cooling or a material change be made to prevent cracking of the thrust plate. Also, mounting pad seals for the afterburner fuel pump should be improved to prevent leakage in this area (page 14).

*18. First stage turbine nozzles be redesigned to provide a greater flow of cooling air over the inner band. There should also be a greater allowance for movement during temperature change either by segmenting the inner band or allowing the inner end of the vanes to float in the inner band, instead of the rigid weld assembly now used (page 15).

*19. An interference fit be designed into the number one bearing housing to prevent rotation of the number one bearing outer race (page 15).

FIGURES ——— 1 thru 14



MAJOR ENGINE SECTIONS

FIGURE 1

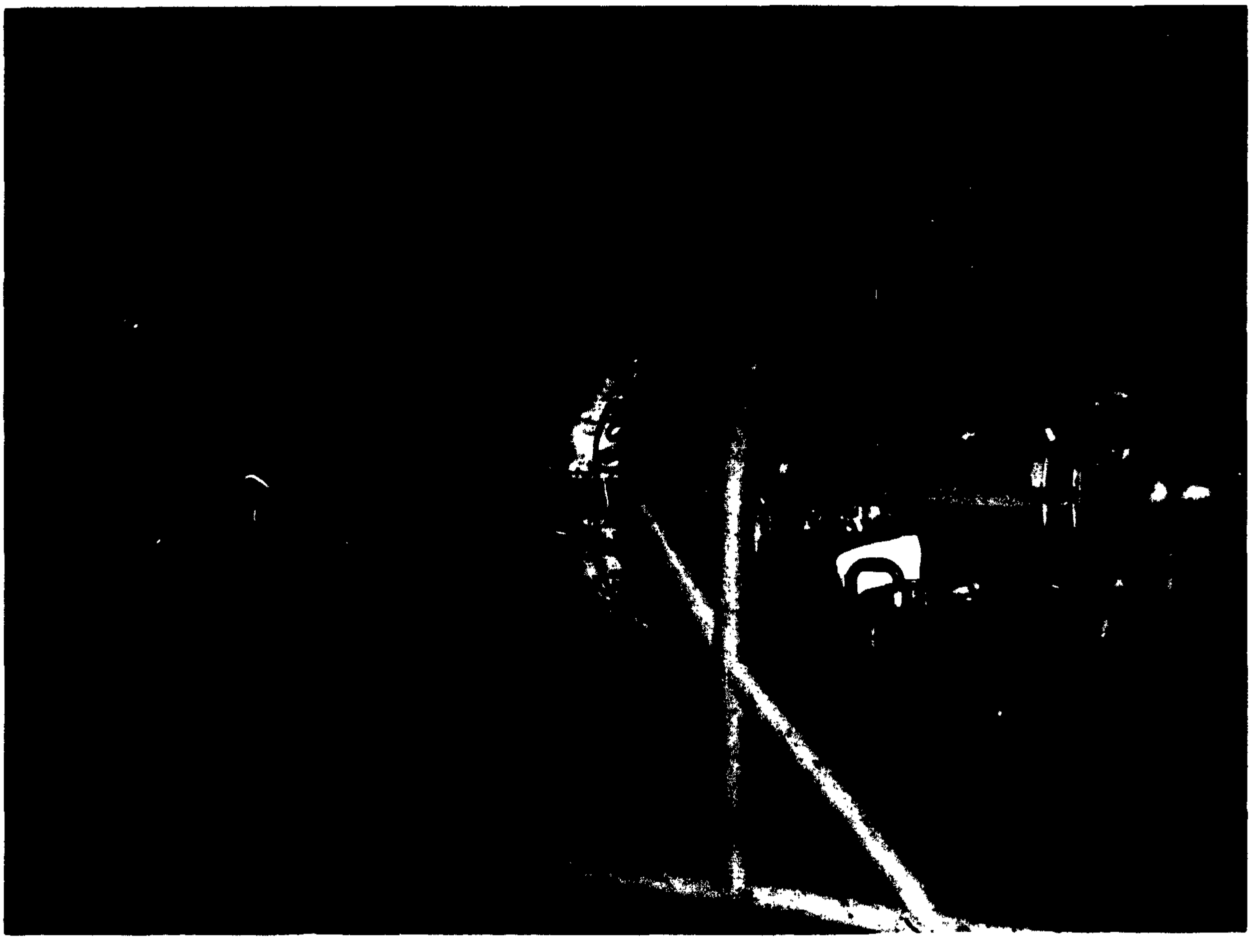


FIGURE 2
J85-GE-5 ON ENGINE REMOVAL STAND

T-38A AIRSTART ENVELOPE
FIGURE 3

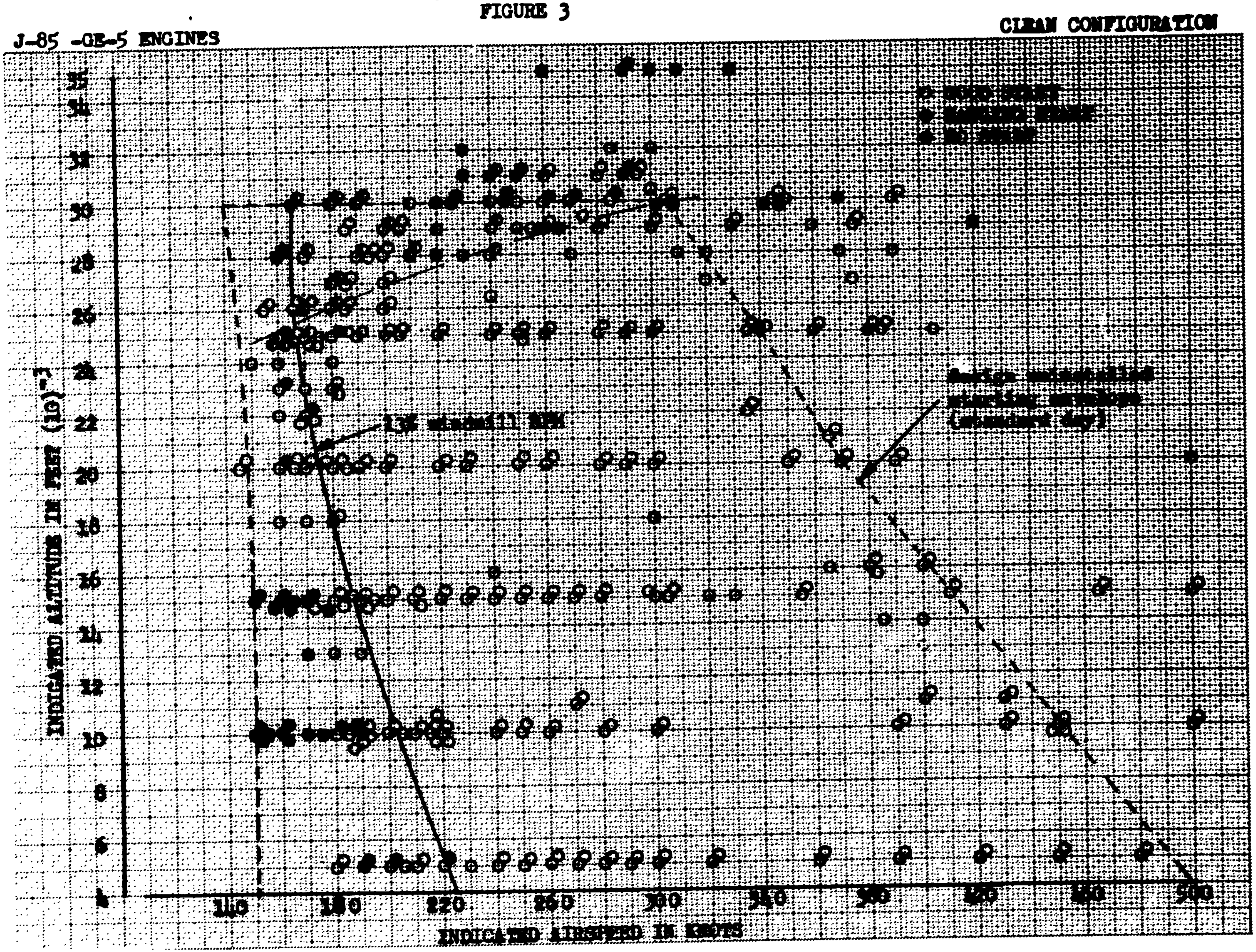
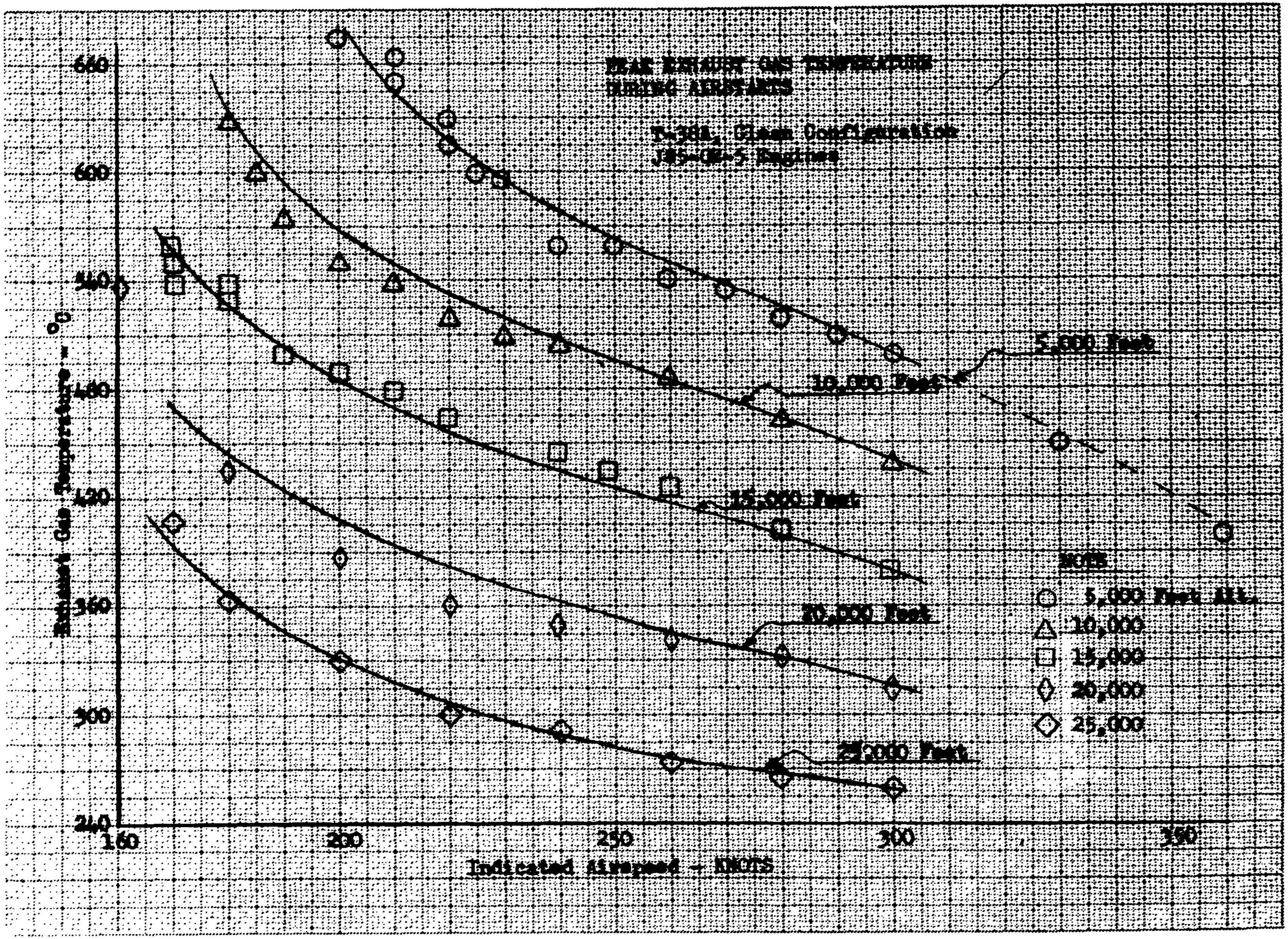
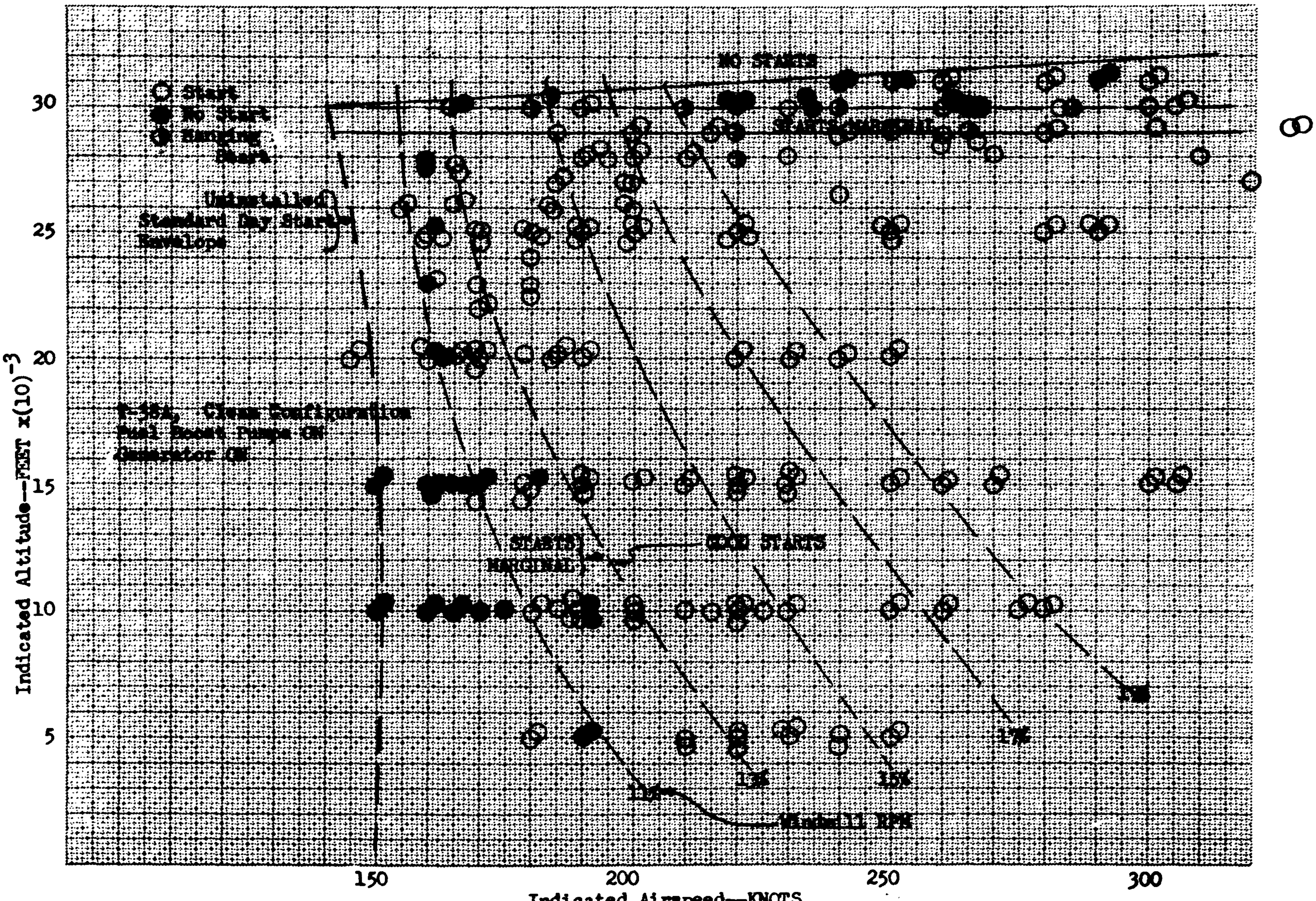


FIGURE 4



PEAK EXHAUST GAS TEMPERATURE
DURING AIRSTARTS
T-38A, Clean Configuration
J85-GE-5 Engines
5,000 Feet
10,000 Feet
15,000 Feet
20,000 Feet
25,000 Feet
NOTE
5,000 Feet Alt.
10,000
15,000
20,000
25,000
660
600
540
480
420
360
300
240
160
200
250
300
350
Exhaust Gas Temperature - °C
Indicated Airspeed - KNOTS



J85-GE-5 ENGINE WINDMILL AND AIRSTART CHARACTERISTICS

FIGURE 5

FIGURE 6

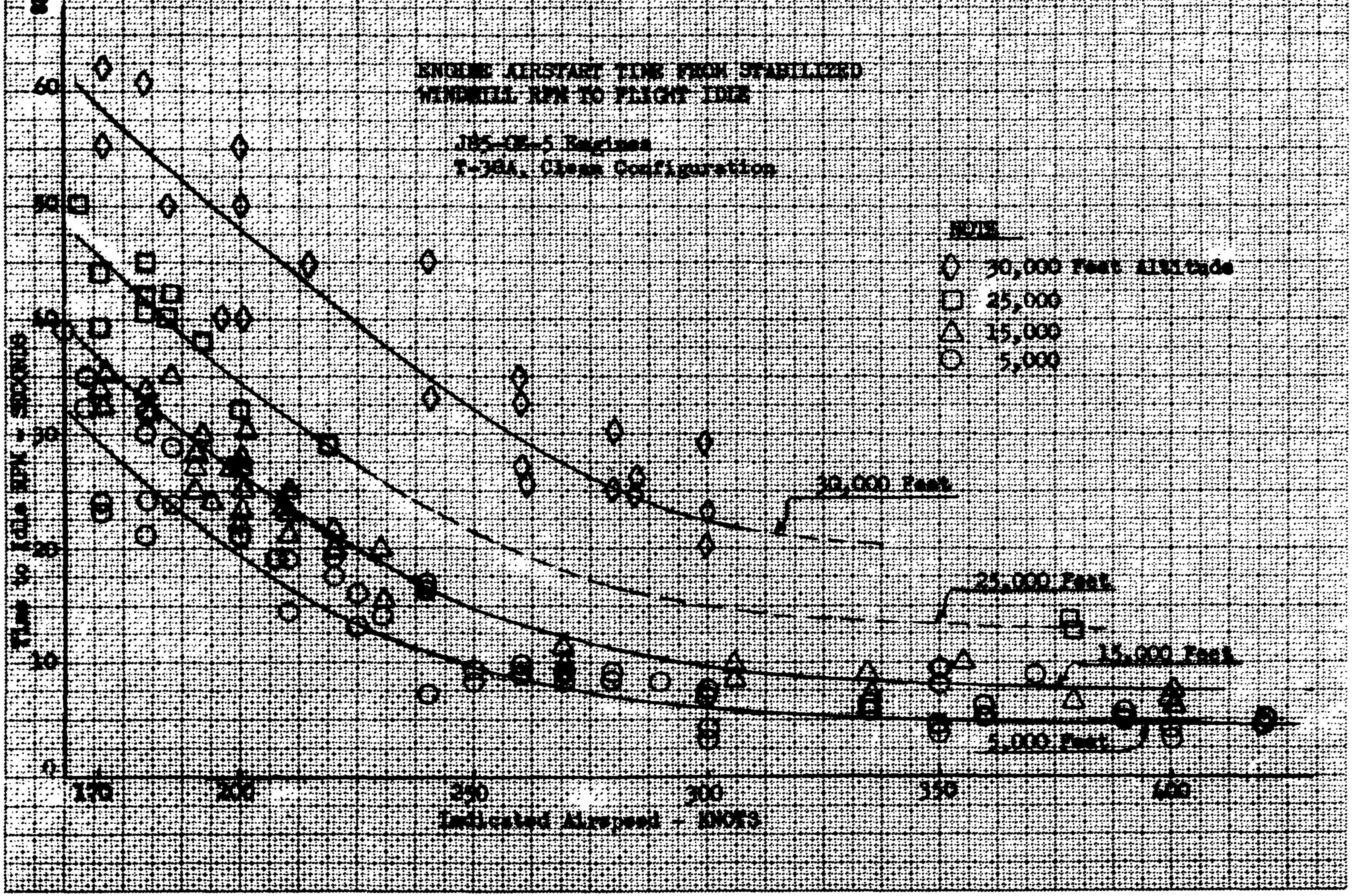
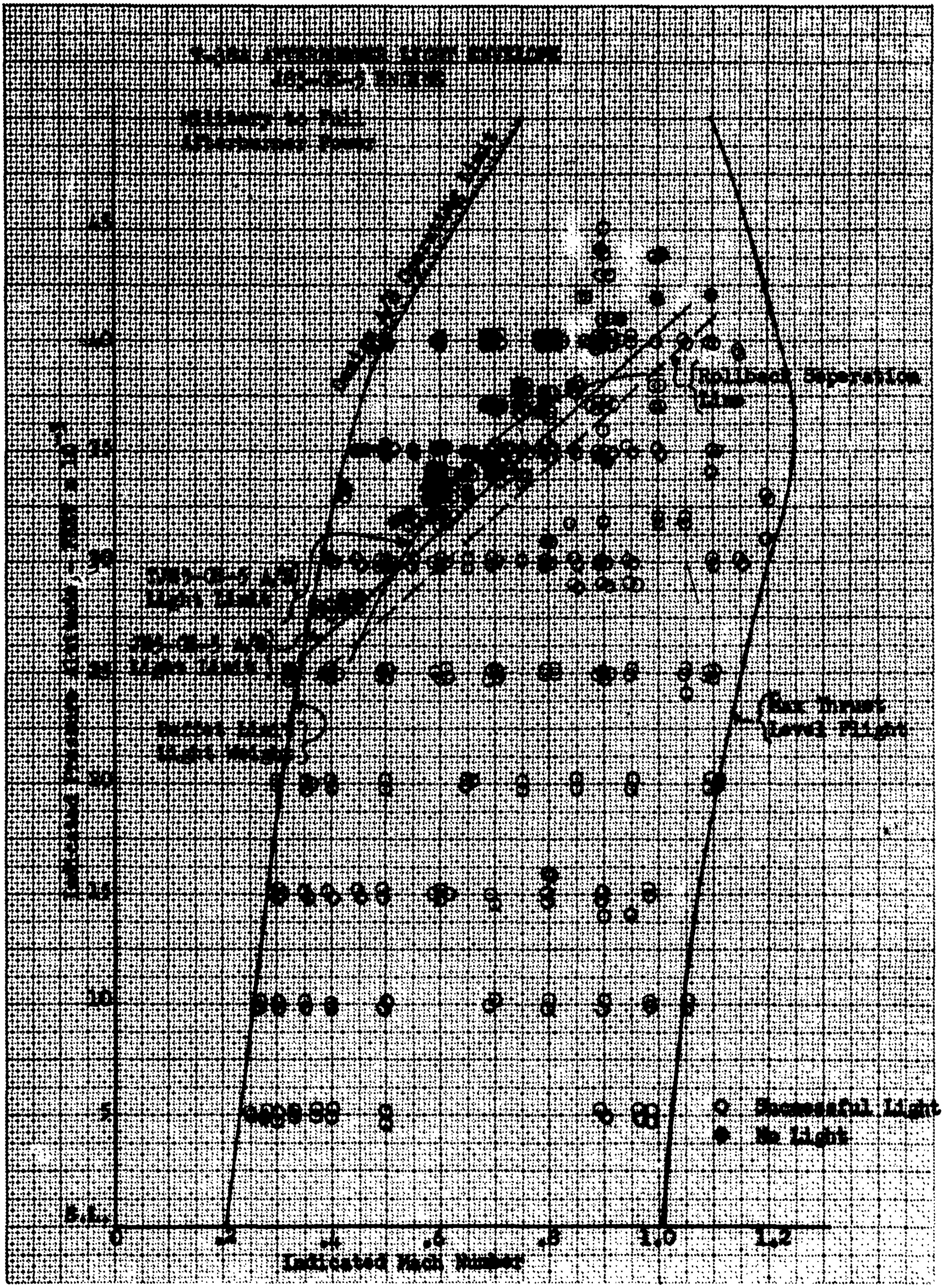

ENGINE AIRSTART TIME FROM STABILIZED
WINDMILL RPM TO FLIGHT IDLE
J85-GE-5 Engines
T-38A, Clean Configuration
NOTE
30,000 Feet Altitude
25,000
15,000
5,000
30,000 Feet
25,000 Feet
15,000 Feet
5,000 Feet
Time to Idle RPM - SECONDS
Indicated Airspeed - KNOTS
0
10
20
30
40
50
60
170
200
250
300
350
400

FIGURE 7



Rollback Separation Line
Max Thrust Level Flight
Successful Light
No Light
Indicated Mach Number
S.L.
0
.2
.4
.6
.8
1.0
1.2
5
10
15
20
25
30
35
40
45

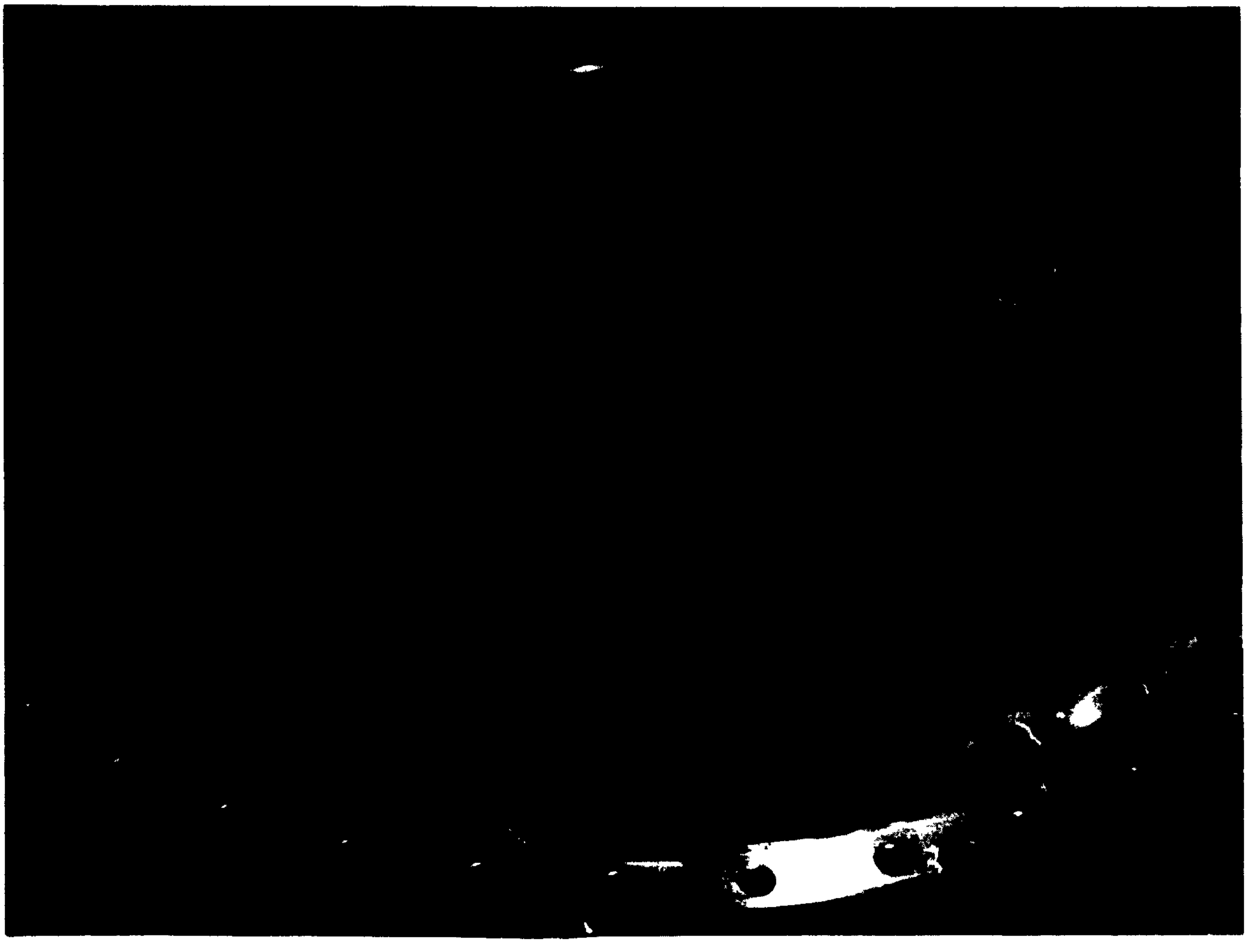
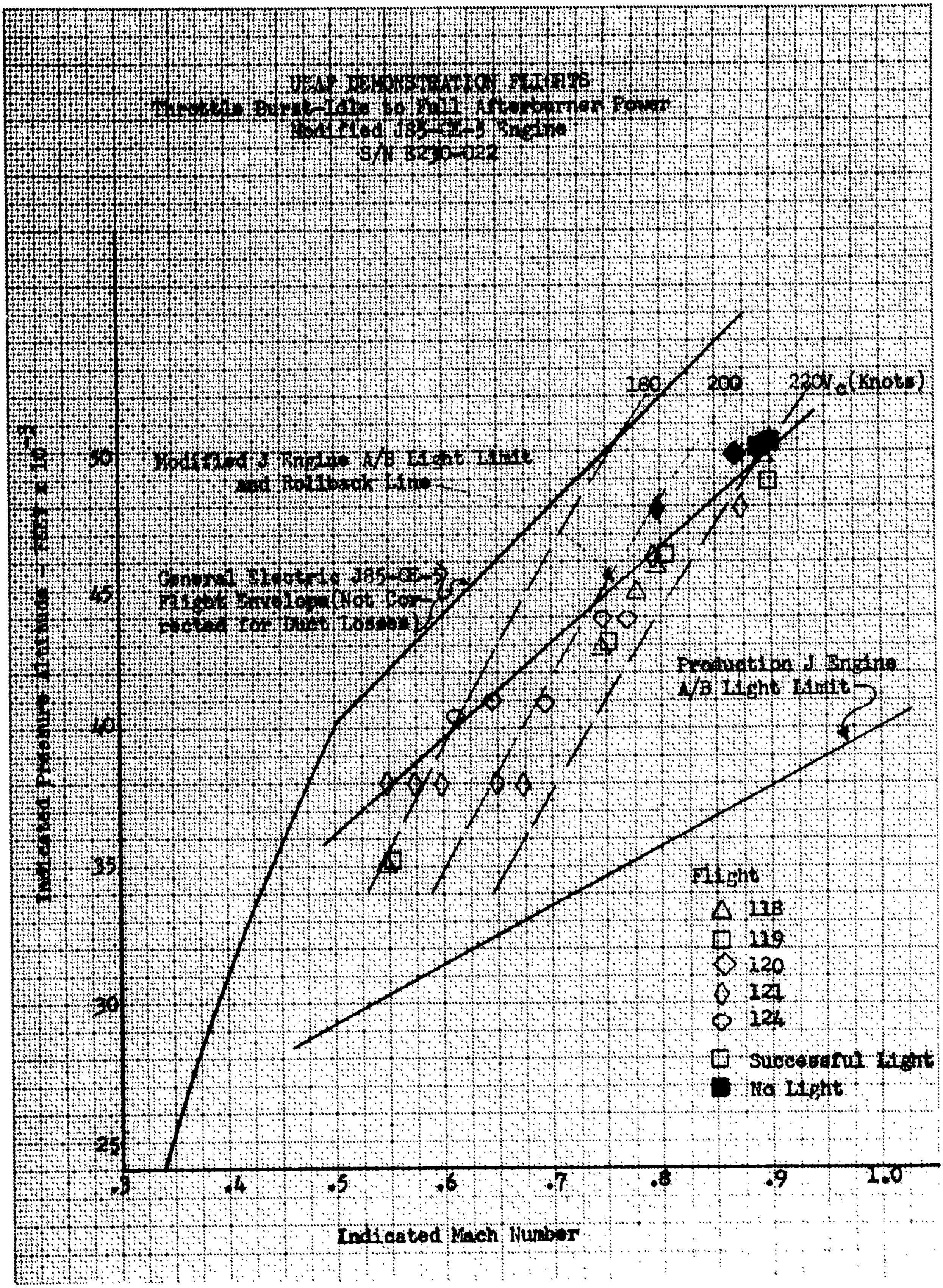


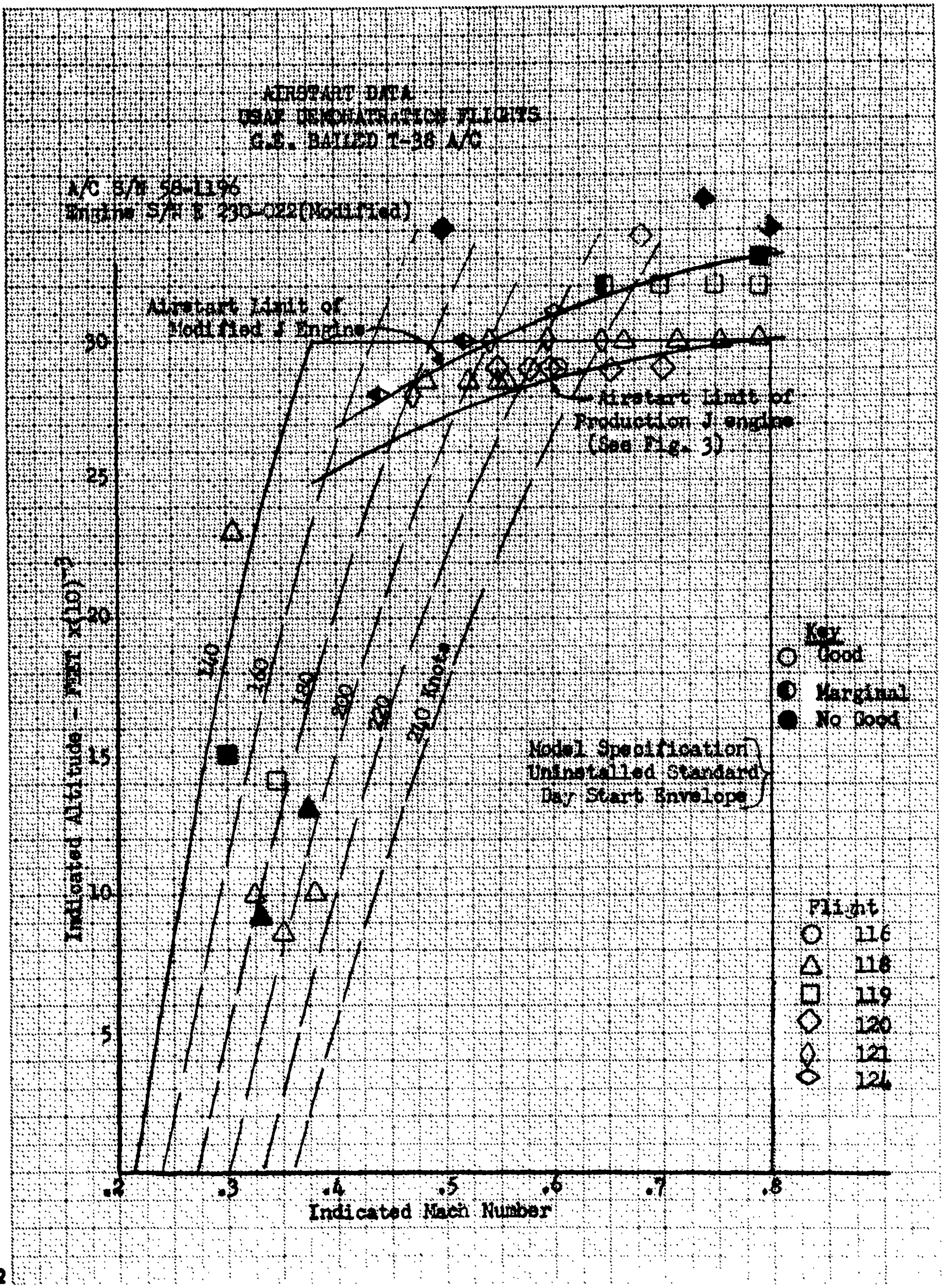
FIGURE 8
CRACKS IN FIRST STAGE
TURBINE NOZZLE

FIGURE 9



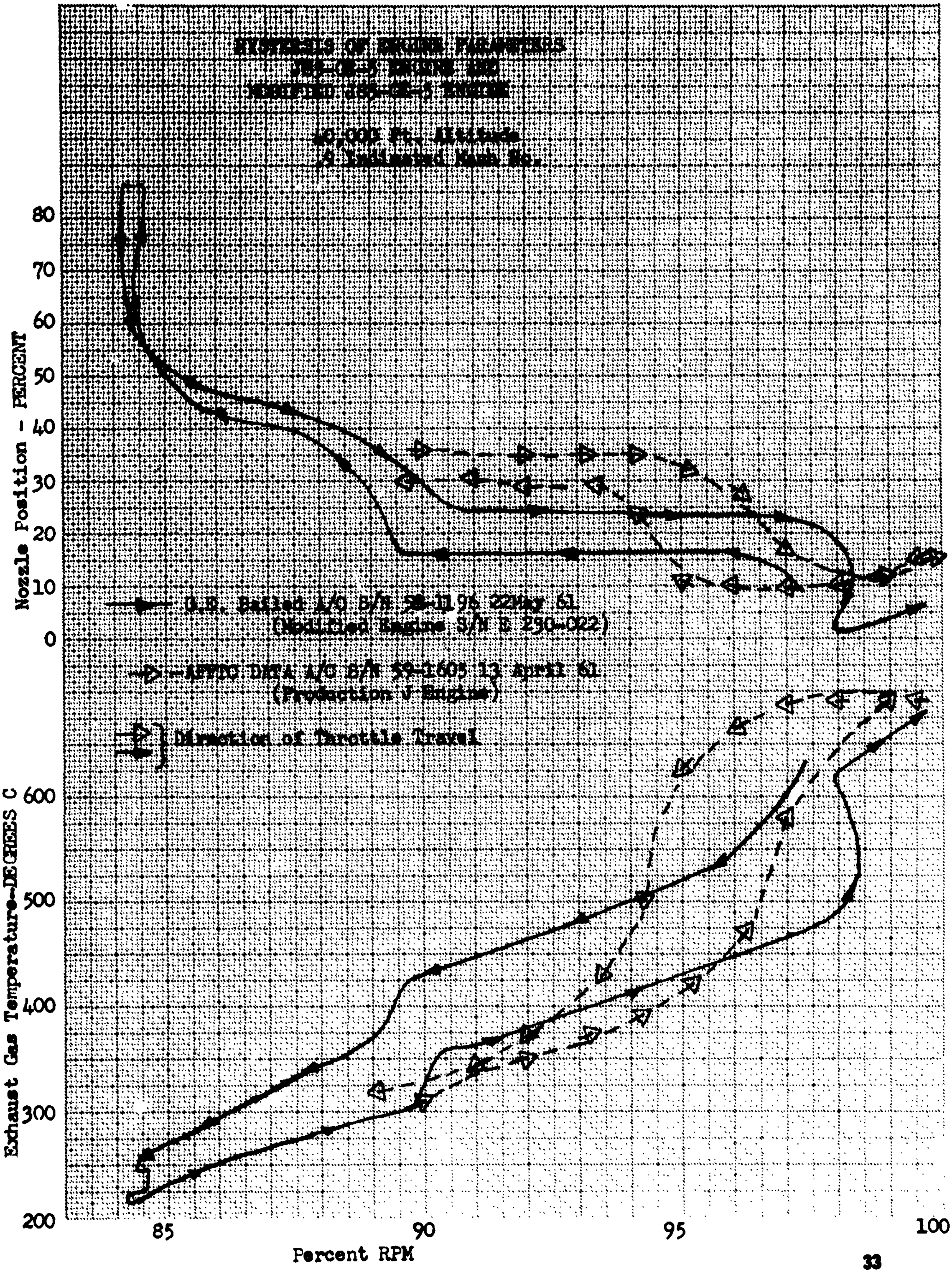
USAF DEMONSTRATION FLIGHTS
Throttle Burst-Idle to Full Afterburner Power
Modified J85-GE-5 Engine
S/N B230-022
180
200
220V$_c$ (Knots)
Modified J Engine A/B Light Limit and Rollback Line
General Electric J85-GE-5 Flight Envelope (Not Corrected for Duct Losses)
Production J Engine A/B Light Limit
Flight
118
119
120
121
124
Successful Light
No Light
Indicated Pressure Altitude - Feet x 10^3
50
45
40
35
30
25
.3
.4
.5
.6
.7
.8
.9
1.0
Indicated Mach Number

FIGURE 10



AIRSTART DATA
USAF DEMONSTRATION FLIGHTS
G.E. BAILED T-38 A/C
A/C S/N 58-1196
Engine S/N E 230-022(Modified)
Airstart Limit of Modified J Engine
Airstart Limit of Production J engine (See Fig. 3)
140
160
180
200
220
240 Knots
Model Specification Uninstalled Standard Day Start Envelope
Key
Good
Marginal
No Good
Flight
116
118
119
120
121
124
Indicated Altitude - FEET x(10)^-3
Indicated Mach Number

FIGURE 11



40,000 Ft. Altitude
Nozzle Position - PERCENT
80
70
60
50
40
30
20
10
0
G.E. Bailed A/C S/N 58-1196 22May 61
(Modified Engine S/N E 290-022)
AFFTC DATA A/C S/N 59-1605 13 April 61
(Production J Engine)
Direction of Throttle Travel
Exhaust Gas Temperature-DEGREES C
600
500
400
300
200
85
90
95
100
Percent RPM

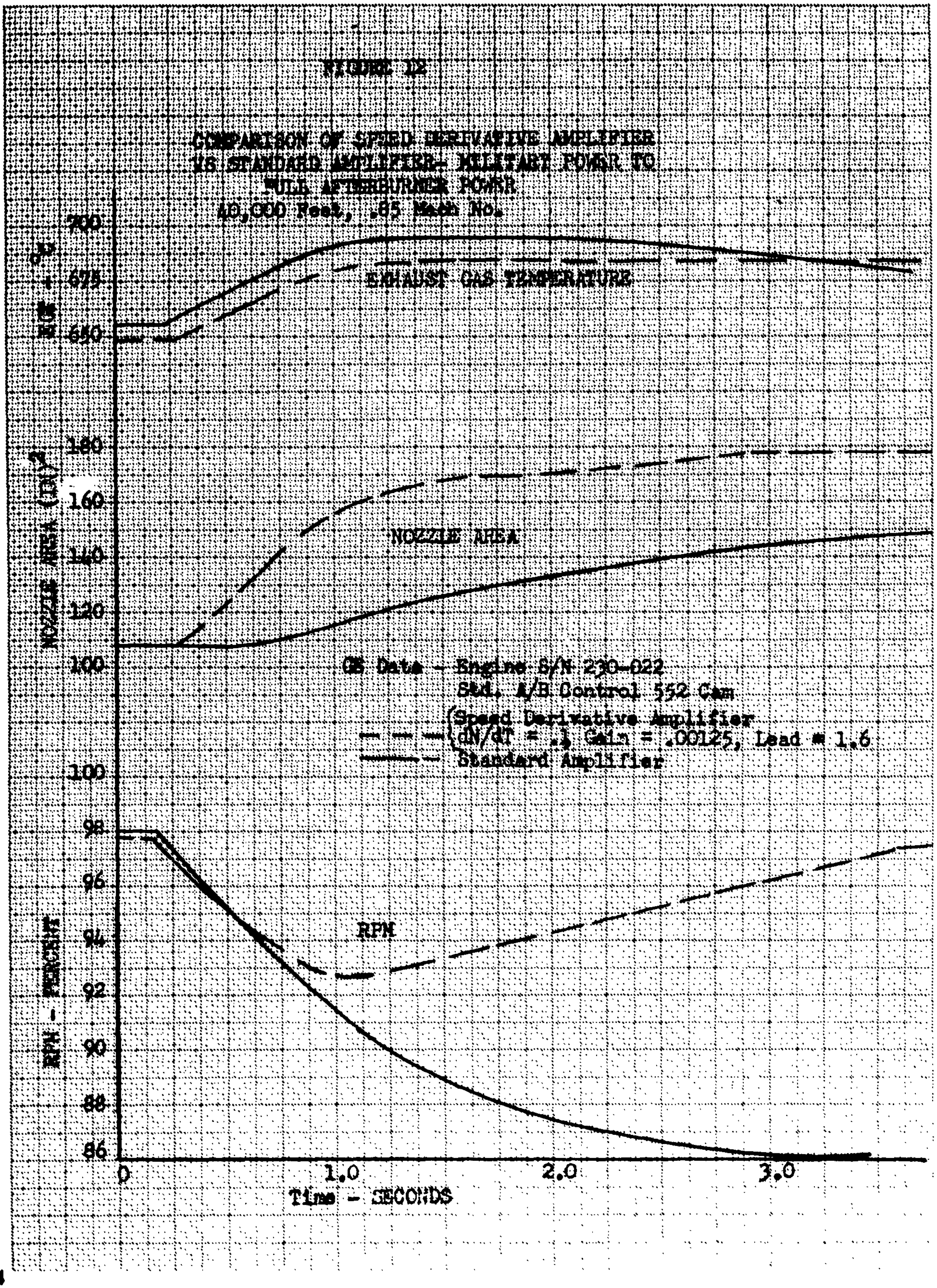


FIGURE 12
COMPARISON OF SPEED DERIVATIVE AMPLIFIER
VS STANDARD AMPLIFIER— MILITARY POWER TO
FULL AFTERBURNER POWER
40,000 Feet, .85 Mach No.
700
675
650
EXHAUST GAS TEMPERATURE
180
160
140
120
100
NOZZLE AREA $(IN)^2$
NOZZLE AREA
GE Data – Engine S/N 230-022
Std. A/B Control 552 Cam
Speed Derivative Amplifier
dN/dT = .1, Gain = .00125, Lead = 1.6
Standard Amplifier
100
98
96
94
92
90
88
86
RPM – PERCENT
RPM
0
1.0
2.0
3.0
Time – SECONDS

FIGURE 13

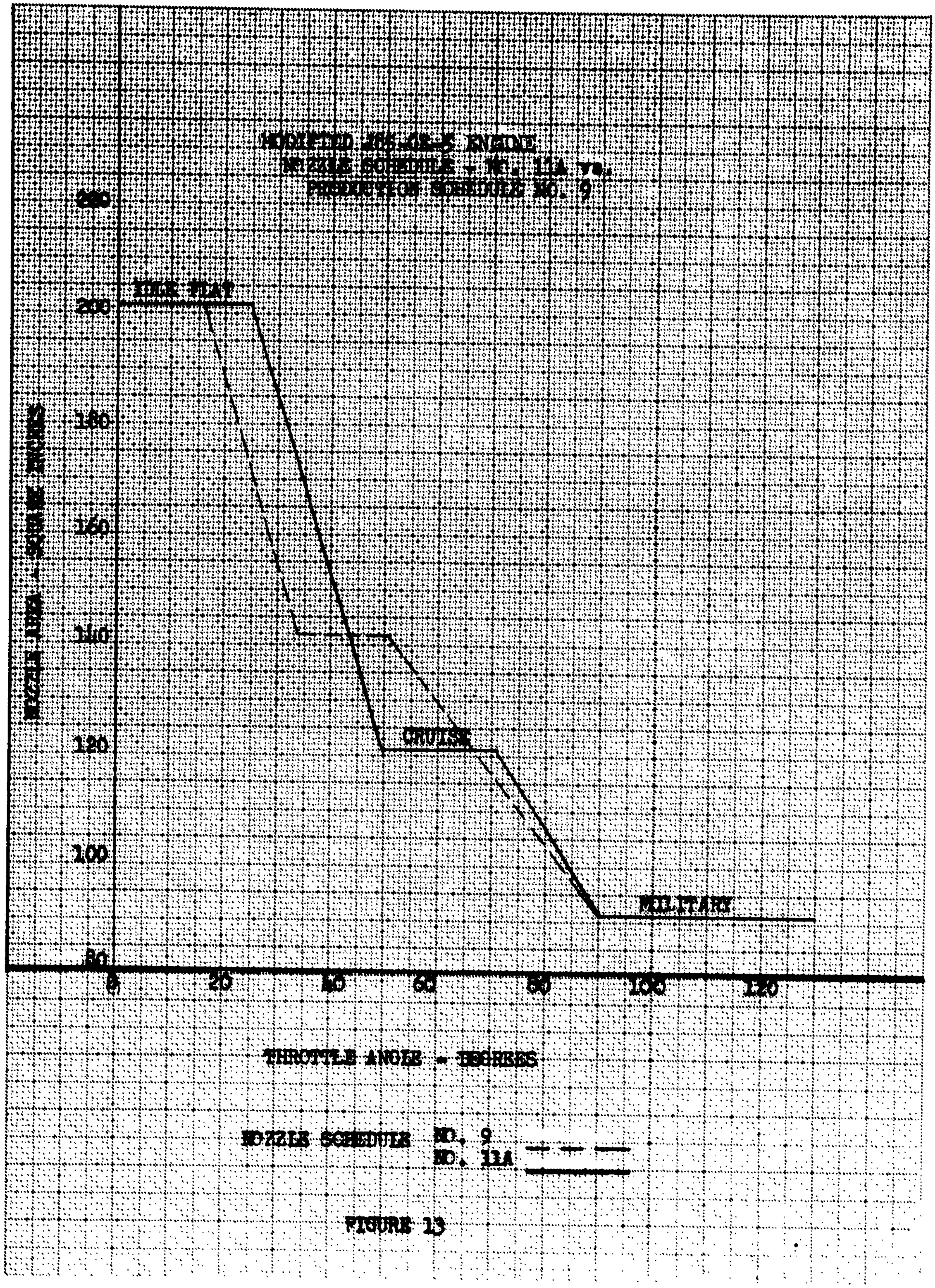


FIGURE 13

FIGURE 14

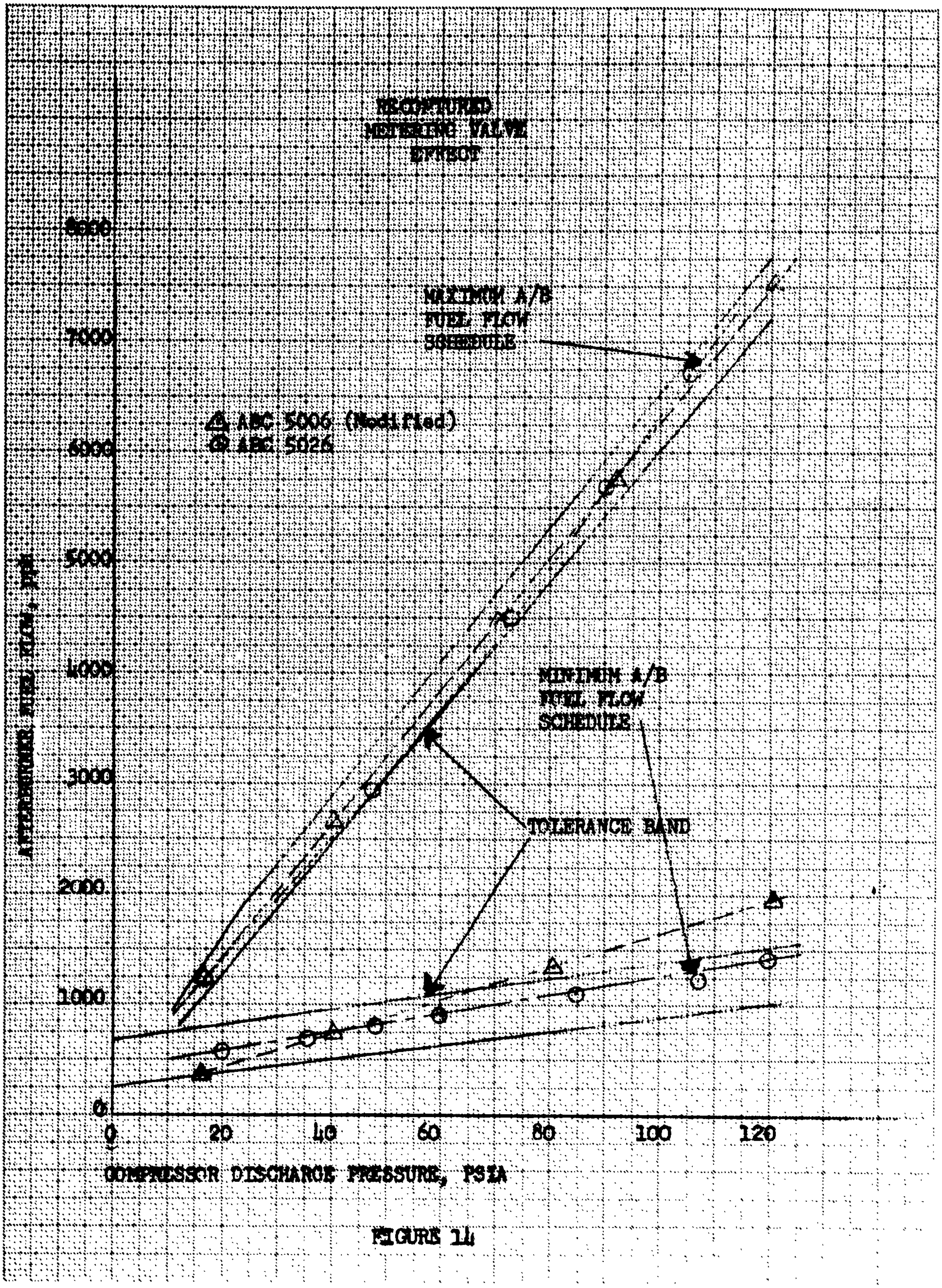


FIGURE 14

APPENDIX I

UNSATISFACTORY REPORTS

UR No.	Date	Description
61-59	10 Mar 61	Failure of main fuel control governor pilot valve piston causing engine overspeed.
61-70	25 Mar 61	Cracked inner band of first stage turbine nozzle.
61-79	4 Apr 61	Static lube oil leak from No. 1 bearing.
61-88	12 Apr 61	Insufficient information on AFTO Form 44 as received from contractor.
61-100	2 May 61	Worn front frame casing due to No. 1 bearing rotation.
61-101	1 May 61	Cracked combustion liner.

APPENDIX II

CHANGES IN J85-GE-5 ENGINE FROM YJ85-GE-5

Item	Changes
Compressor front frame	New anti-icing air configuration. New method of bullet nose attachment. Silver stationary air seal replaces filled honeycomb to reduce labyrinth tooth wear.
Compressor rotor	Stud type compressor rotor for ease of maintenance, increased stability. Flow duct added to increase flow of pressurizing air to the No. 1 bearing sump seal. Double eighth stage air seal to reduce the amount of leakage.
No. 2 bearing	Increased radial clearances. Reduced thrust loadings.
Combustion liner	Improved cooling airflow. Eliminate dummy ignitor plug port. Material change.
Fuel nozzles	Stiffened for vibration "detuning". Swirl type air shroud.
First stage turbine nozzle	Welded rather than brazed construction. Increased area.
Turbine wheel	Improved cooling airflow.
Turbine casing	Machined first stage shroud, honeycomb second stage shroud for reduced running clearances. Material change.
Diffuser assembly	Short center body reduces pressure losses. New method of liner attachment. Improved A/B spraybars. Redesigned flameholder for better flame propagation.
Afterburner	Liner cooling airflow and method of attachment improved.
Variable exhaust nozzle	Redesigned nozzle leaves, seals, and links.
No. 3 bearing	Outer race pinned to prevent rotation.

Eighth stage leakage air system	Duct strengthened. New sliding seal on duct. Redesigned poppet valve for better reliability.
Anti-icing valve	Better flow characteristics, higher temperature capability.
Compressor bleed valves	Cam actuated valve for better endurance and temperature capability.
Main fuel control	New fuel schedules. Aspirator type T_2 sensor.
Afterburner control	New fuel schedule. New variable exhaust nozzle schedule. Nozzle lockout switch for improved engine accelerations. Additional rigging provisions to facilitate aircraft rigging.
Afterburner pump	Redesigned shaft fuel seal.
Exhaust nozzle power unit	Internal parts strengthened. Reverse rotation protection. Stops on the input lever. Spring-type override on the input linkage.
Lube tank	Minor improvements for better reliability.
Exhaust gas temperature amplifier	Modular design for ease of repair. Ruggedized components. Waterproof construction. Increased stability.
Ignition unit	Output voltage increased. Improved temperature and vibration capability.
Variable exhaust nozzle actuators	Dry film lubricant for better life and higher temperature capability. Ball-screw mechanism redesigned.
Bleed valve and inlet guide vane actuating system	Bell crank strengthened at pivot points. Linkage strengthened at connecting points. Improved attachment of levers to inlet guide vanes.
Overspeed governor	Incorporated on later production engines, to be retrofitted on early production engines.
External configuration	Rerouting of plumbing and electrical leads to give a cleaner engine configuration. Relocation of components to better temperature and vibration environments and to solve airframe interference problems.
Lube system seals	"Viton A" O-rings used for better service life.
Performance	Increased exhaust gas temperature. Increased thrust. Increased engine airflow. Improved specific fuel consumption.

ASTIA DOCUMENT NO. AD-

Air Force Flight Test Center
Flight Test Engineering Division
Edwards AFB, California

Category II YH and J85-GE-5 Engine Follow-On Evaluations By Thomas H. Hobbs, Captain, USAF, and Swart H. Nelson Major, USAF. October 1961. 39 Pages. (AFFTC TR-61-54)

This report presents the results of three distinct engine evaluation programs: evaluation of YJ engine component improvements, many of which are common to the J engine; evaluation of J engines in the production configuration now being delivered in the first operational T-38 aircraft; most recently, evaluation of a modified production J engine (General Electric "Operation Nutcracker").

Significant improvements in engine operation were noted in these evaluations over YJ engines used during the Category II systems tests. Modifications tested will bring the J engine up to a reasonably acceptable power plant from an operational standpoint; however, certain component deficiencies still limit the service life. Evaluation of the production J engine indicates that the first stage turbine nozzle and combustion liner

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service life is very short. Also, excessive oil venting occurred on all engines. The J engine modifications provided improved operation in all the above areas with the following results: afterburner lights are reliable to 50,000 feet above .90 IMN,, and throughout the flight envelope below 40,000 feet; RPM rollback and engine flameout during throttle burst from idle to full afterburner was eliminated below 40,000 feet within the normal flight envelope and significantly improved above 40,000 feet; reliable airstarts were made at 30,000 feet above 200 knots IAS (.54 Mach).

Two serious deficiencies exist in the modified J engine which should be corrected; engine stalls and/or flameout occur in cruise flight conditions during throttle movements from cruise power to military or afterburner power while at high altitude and low indicated airspeeds; and hysteresis in engine operating parameters has been a problem on all J and YJ engines.

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FOR ERRATA

AD 266 168

THE FOLLOWING PAGES ARE CHANGES

TO BASIC DOCUMENT

AD 266168

HEADQUARTERS
AIR FORCE FLIGHT TEST CENTER
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE
EDWARDS AIR FORCE BASE, CALIFORNIA

AD INEXPLORATA

REPLY TO ATTN OF: FTFED/Mr. Tucker/33251

SUBJECT: Inclusion of Project Office Comments

TO: ASTIA (TIPCR)
Arlington Hall Sta
Arlington 12, Va

JAN 2 1962

1. As verbally agreed upon between the undersigned and the T-38 SPO, ASD, the list of status of actions being taken as a result of recommendations in AFFTC-TR-61-54, "Category II YJ and J85-GE-5 Engine Follow-On Evaluations," is provided as an attacnment for insertion following page 22. The status of action is as of September 1961.

2. Request that the attached information be made a permanent part of the basic report.

FOR THE COMMANDER

Clayton L. Peterson
CLAYTON L. PETERSON
Colonel, USAF
Director, Flight Test

1 Atch
Project Office Comments

AFFTC-TR-61-54 Attachment to follow Page 22.

Category II YJ and J85-GE-5 Engine Follow-On Evaluations.

PROJECT OFFICE COMMENTS

This attachment provides the ASD Project Office action to the consolidated recommendations in this report. Numbers correspond with the numbers in the recommendations section.

The action being taken on problems for which fixes were not specifically tested appears satisfactory. The status of action indicated is as of September 1961.

A. Operational Improvements.

(1) The group A recommendations of the subject report and resulting engineering change proposals (ECPs) pertaining to improving the J85-GE-5 engine operation have been reviewed and approved by ASD, contingent upon successful completion of all phases of testing. Introduction of these items into production engines was scheduled for October 1961. They are as follows:

(a) Speed derivative amplifier dn/dt .1, GAIN .00125. (ECP 85N-12).

(b) No. 11A Nozzle schedule. (ECP 85L-43).

(c) New A_8 limit schedule. (ECP 85L-43).

(d) 553 Fuel schedule. (ECP 85L-41).

(e) Optimize pilot burner fuel flow. (ECP 85L-43).

(f) GLA ignition system. (ECP 85L-11).

(g) Lightweight metering valve spring and trim bellows. (ECP 85L-29).

(h) Recontoured metering valve (A/B fuel control). (ECP 85L-43).

(2) The present J85-5 engine stall and flame-out problem while at high altitude, low-speed flight conditions when going from cruise power to military or afterburner, is expected to be eliminated by the introduction of a new compressor which is now being tested. The compressor configuration is expected to be evaluated by January 1962.

The airframe contractor's program to define ingestion effects of high temperature secondary cooling air may well define airframe modifications which will give additional relief in this problem area.

B. The group B, recommendations are not applicable. The alternate recommendations are being accepted.

C. Additional AFFTC Recommendations.

(6) The present throttle hysteresis problem is expected to be reduced to negligible level by introduction of the new A_8 cam schedule change. Also, new rigging instructions have been issued which partially correct this problem.

(7) This will be introduced at the flight handbook review to take place at NORAIR, 11-15 September 1961.

(8) Elimination of oil loss through overboard vents due to aircraft attitude and loading during maneuvers has since been corrected by class II change which replaces the inverted flight vent ball inside the lube tank with a cylindrical body check valve.

(9) The engine and airframe contractors will be notified of this recommendation. A possible solution might be marking of dip stick with FULL (HOT) mark and FULL (COLD) mark. MAAMA has been made aware by letter that T.O. instructions for oil servicing are considered inadequate.

(10) The TACAN is expected to be qualified within the month of September. Aircraft produced prior to mid-August are restricted to VFR until a reliable TACAN is installed.

(11) Endurance testing of a seal is now in progress. A carbon seal which incorporates a teflon wiper is being tested at General Electric. Preliminary results indicate excellent sealing action at low rotor speeds.

(12) OCAMA has been made aware by message of this recommendation for their action.

(13) General Electric Company statement of need number 61-D-0044 has been received by ASD which requests main fuel control modifications providing adequate lubrication and clearance between the internal governor valve and sleeve. A contingent approval has been given for this statement of need. Approximate date for fix is January 1962.

(14) Testing of modified fuel nozzles which are to prevent clogging with carbon deposits is being conducted by General Electric. These new fuel nozzles are expected to be available by January 1962.

(15) Extended service life of the combustion liner is expected due to a different welding procedure being utilized which will eliminate fatigue cracks at the aft end of the liner. Cracking of the liner is expected to be decreased through use of a better temperature profile in the combustor. Combustor liners utilizing the new welding procedure are expected to be available March 1962. Repair limits will be determined by OCAMA under advisement of the General Electric Company.

(16) OCAMA has been made aware of this recommendation. The engine contractor has been requested to eliminate bowing of turbine shrouds.

(17) Incorporation of a thinner mating ring in the accessory drive housing is presently undergoing endurance testing during August 1961 with no report of leakage. An A/B fuel pump change was initiated by General Electric to provide better lubrication and cooling flow to the A/B thrust bearing by plugging two fuel passages in the A/B pump, thus providing series flow instead of the previous parallel flow. The series flow will prevent clogging in the remaining passages due to the greater fuel pressure resulting, thereby insuring adequate lubrication of the thrust bearing.

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(19) A newly designed number one bearing having a pinned outer race is now on test. Introduction of this bearing is expected on October 1961 engines.

AD 266168

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AD 266 168

END CHANGE PAGES